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RECENT SOLAR OBSERVATIONS AT HAVERFORD

By WALTER M. MITCHELL

During the past year observations of solar phenomena have been made at the Haverford College Observatory. The instrument used was the 10 in. (25.4 cm) equatorial, with mounting and object-glass of 150 in. (381 cm) focal length made by the Clarks; with this a somewhat novel form of spectroscope was used.

It was manifestly impossible to attach a powerful, and consequently heavy spectroscope to this small instrument in the ordinary manner. Acting upon a suggestion from Professor Hale, it was decided to mount the spectroscope upon the telescope tube itself, and by suitable reflecting devices to direct the beam of light into it in that position.[1] This was accomplished as follows: The beam of light coming from the object-glass of the telescope in the direction *OA*, Fig. 1, is reflected by the 90° prism *A* in a direction at right angles to its former course. The image is formed at the slit *S* (the slit is actually turned 90° in its own plane, from the position shown in the figure). The light passing through is again reflected at a right angle by the 90° prism *B*, and thence passes through the lens *L* of 3 in. (7.6 cm) aperture and 39 in. (99 cm) focal length, to the grating at *G*. The grating and lens are inclined slightly, so that the returning beam of light passes just above the prism *B* and forms the image of the spectrum at the eyepiece *E*.

As the solar image formed by the 10-inch object-glass was rather small it was decided to increase it by means of an enlarging lens.

[1] It has since been noticed that a similar form of instrument was suggested by Wadsworth some years ago in the *Astrophysical Journal*, 1, 240, 1895.

This was placed at N, between the object-glass and the first prism. This lens is of $2\frac{3}{4}$ inches (7 cm) aperture and 6 inches (15.2 cm) negative focal length, and was made by the Clark Corporation. The focal length employed, resulting from this combination, was 30 feet (914 cm), giving a solar image of $3\frac{1}{4}$ inches (8.3 cm) diameter.

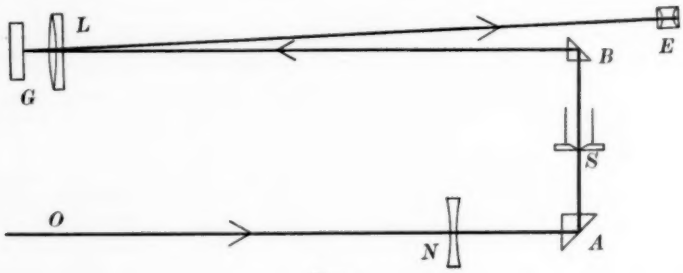

FIG. 1

By racking the lens N toward or away from the object-glass the focal plane for rays of any wave-length can be brought into coincidence with the plane of the slit, an adjustment of the greatest importance, otherwise secured with difficulty in this construction. Moving the enlarging lens in this manner slightly alters the size of the image on the slit, but this is of no consequence.

Plate III, Fig. 2 shows the spectroscope in position on the telescope with one side and the top removed. As seen from this the spectroscope is constructed largely of wood. The base is of $\frac{1}{2}$ inch oak, the sides and top of $\frac{3}{8}$ inch poplar, the whole being well braced. All the wood was thoroughly saturated with hot paraffine before the instrument was finally assembled, in order to prevent absorption of moisture and subsequent warping.

The grating was the $4\times2\frac{1}{2}$ inch (10.1×6.4 cm) Rowland grating, 20,000 lines to the inch (7874 to the cm) of the Halsted Observatory, formerly used by the writer while at Princeton. The writer is greatly indebted to the Princeton University Observatory for granting the loan of this grating. Completed, the weight of the spectroscope (including the grating) is less than 50 pounds (23 kilos).

Owing to the great difference between the ratio of aperture to focal length, 1:36 in the equatorial with enlarging lens, and 1:13.5 in the spectroscope, the whole surface of the grating is not illuminated.

PLATE III

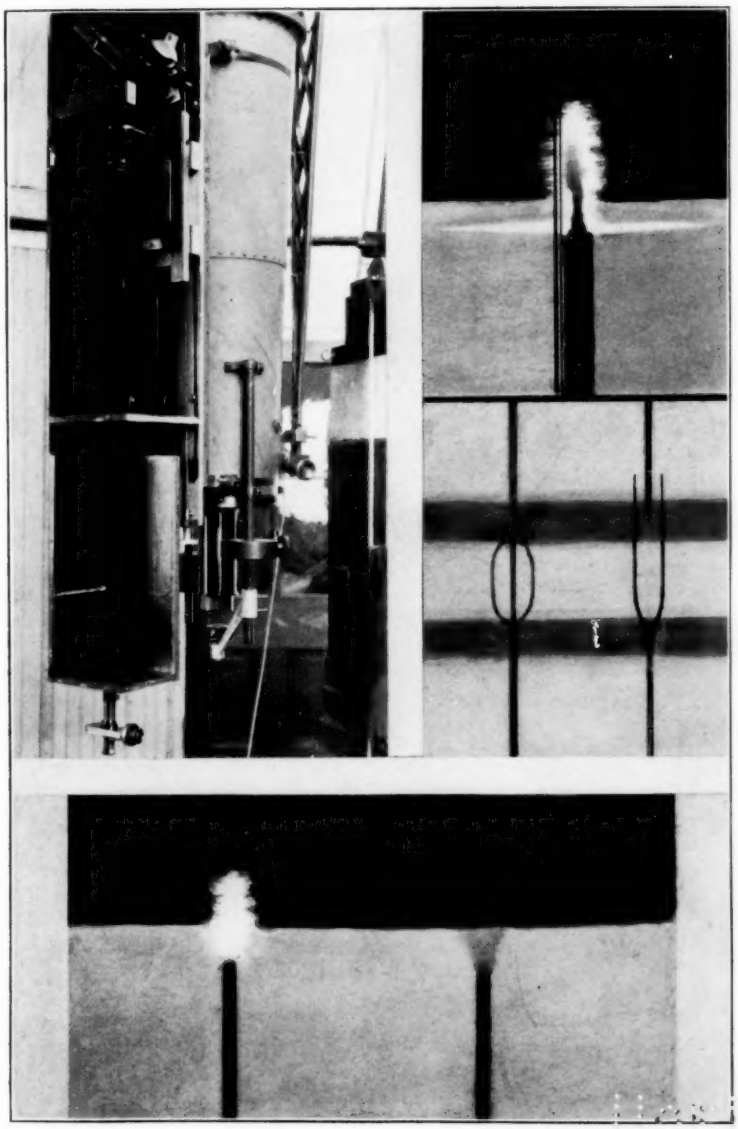

FIG. 2

FIG. 4

FIG. 5 (*a*) and (*b*)

FIG. 3

(*a*) (*b*)

But as a large image is more desirable in solar investigations than illumination, the latter had to be sacrificed. Notwithstanding the loss of light from this cause and from the numerous reflections, it is possible to observe in the third-order spectrum as far as λ 6200. Below this it is best to use the second order, although the C line can readily be seen in the third order by screening the eye from extraneous light.

It is interesting to compare this instrument with the 23-inch refractor and Brashear spectroscope (*Astronomy and Astro-Physics*, **11**, 292, 1892) at Princeton, since the same grating has been used in both instruments and the focal lengths of the main telescopes are the same. Taking into consideration the cost and the ease of manipulation, the advantage is obviously on the side of the smaller instrument. The fixed position angle of the slit and the loss of light are the only serious objections to the type of instrument used at Haverford; both of these are of importance in chromospheric observations, while for sun-spot work the latter only is a disadvantage. But, as far as actual efficiency is concerned, neither of these objections is so great as to render the Haverford instrument greatly inferior to that at Princeton. The definition is practically equal in the two instruments, while the slightly longer focal length of the Haverford spectroscope is an advantage. Such lines as λ 5264.4 and λ 6248.0 are easily separated in the third-order spectrum, indicating an actual resolving power of 70,000.

There seems to be no objection to the use of an enlarging lens in the manner indicated above; prominences when favorably situated have been seen very satisfactorily, with definition equal to that of the Princeton refractor. On account of wood entering so largely into the construction of the spectroscope it is not sufficiently rigid to be used for photographic work, but for the visual observations for which it was designed, it performs admirably.

This rather lengthy account of the instrument has been given with the hope that others desirous of making solar observations may not feel handicapped by reason of small instruments, but will profit by the writer's experience. By following this design or some modification of it, a really efficient solar spectroscope may be constructed at a very small cost, provided of course that a good grating is available.

OBSERVATIONS

With the spectroscope just described it has been possible to verify visually Hale's photographic observations of the Zeeman effect in sun-spots.[1] The method was that employed by Hale at Mt. Wilson of placing a Fresnel rhomb and Nicol prism in front of the slit. The observation was one of great difficulty owing to the extreme faintness of the spectrum, but there was no doubt of the variation in the intensity of the components of the doublet as the Nicol was revolved. In one spot two magnetic fields were found, the same component of the doublet being polarized in opposite directions in the closely adjoining fields.

An interesting chromospheric outburst was observed on January 21, 1909, 7^h to 9^h G. M. T., in a series of bright knots on the sun's east limb. The lines usually present in the spectrum of the chromosphere were very bright, beginning inside the limb and extending beyond it as in Plate III, Fig. 3 (*a*). On running through the spectrum all the dark lines (not belonging to the chromosphere) of intensity 3 or over were seen affected in this region and appeared widened, weakened, and hazy inside the limb, Fig. 3 (*b*). The C line (λ 6563.0) in the chromosphere was much brighter than the spectrum of the photosphere. Inside the limb very bright points, or jets extended from the side of this line; these flashed very decidedly owing to the unsteady seeing. The jets were prolonged in both directions at one time to λ 6165.0 and λ 6564.7, and at a later time to λ 6560.1 and λ 6568.0. It was rather curious to observe the atmospheric lines just below C continuing across the widened and distorted chromospheric line. Fig. 4 is an attempt to show the appearance of C at the time of maximum disturbance, 7^h 35^m. The helium line D_3 was also very bright and showed distortions similar to C, extending to λ 5880.0 and λ 5870.0, with faint atmospheric lines continuing across the chromospheric line. Similar distortion and displacements, but on a smaller scale, were noted in the sodium lines D, and D_2, in λ 5316.79, the *b* lines (b_3 being particularly bright), and the F line.

[1] Observations were made by the writer at Princeton during the winter of 1905–1906 for the purpose of determining whether the then called "reversals" were really such or were Zeeman doublets. A quarter-wave plate was used, but no certain results were obtained and the matter was dropped for the time being.

In Table I are given the lines that were recorded on this date. Columns 1 and 2 are from Rowland's Table, column 3 contains remarks upon the appearance of the line. As fine distinctions in the

TABLE I

Wave-Length	Element	Remarks
4924.107	p *Fe*	Strong (*a*). Y.
5015.80	*He*	Faint, high level line. Y.
5018.629	p *Fe*	Strong (*a*). Y.
5197.743	p *Fe*	Strong (*a*). Y.
5234.791	p *Fe*	Strong (*a*). Y.
5237.493	p *Cr*	Faint (*a*). Y.
5239.992		Faint (*a*). Y.
5264.976		Medium (*a*). Y.
5276.169	p *Fe*	Strong (*a*). Y.
5284.281	*Ti*	Strong (*a*). Y.
5320.220	*Fe*	Faint (*a*)
5325.738		Medium (*a*). Y gives the line λ 5325.4
5336.974	p *Ti*, —	Faint (*a*). Y.
5363.058		Strong (*a*)
5425.464		Strong (*a*) The red component of the double } Y incomplete here
5535.061	*Fe*	Strong (*a*)
5991.600		Medium (*a*)
6122.434	*Ca*	Strong (*b*). Y.
6136.829	*Fe*	Strong (*b*). Y.
6137.915	*Fe*	Strong (*b*). Y.
6141.938	*Fe*, *Ba*	Medium (*a*). Y.
6148.0	*Fe*	Medium (*a*). Not sure which component reverses. Y.
6149.458		Medium (*a*). Y.
6162.390	*Ca*	Strong (*a*). Y.
6191.779	*Fe*	Strong (*a*). Y.
6230.943	*V–Fe*	Strong (*b*). Y.
6238.598		Medium (*a*). Y.
6247.774	p *Fe*	Strong (*a*). Y.
6252.773	*Fe*	Faint (*b*)
6254.4	*Fe*	Faint (*b*). Not sure which component reverses.
6256.572	*Ni–Fe*	Faint (*b*)
6301.718	*Fe*	Medium (*b*). Y.
6302.709	*Fe*	Medium (*b*). Y.
6318.239	*Fe*	Strong (*b*)
6322.907	*Fe*	Strong (*b*)
6344.371	*Fe*	Medium (*a*). Y.
6432.895	*Fe*	Strong (*a*). Y.
6456.603	p *Fe*	Strong (*a*). Y.

estimates of the intensity of chromospheric lines are as a rule unreliable, only three degrees are given: strong, medium, and faint. (*a*) and (*b*) indicate that the lines were affected like (*a*) and (*b*) in Fig. 3. Y indicates that the line is given in Young's revised list of chromospheric lines.

As is usual in outbursts of this kind, only a small percentage of the number of lines affected could be recorded. In comparing this with a similar outburst recorded at Princeton on May 13, 1906,[1] it is to be noted that the usual chromospheric lines were in each case much brighter than under ordinary circumstances. The greater number of the Fraunhofer lines in the earlier instance were doubly reversed (bright with dark center) beyond the limb, while in the later outburst these same lines were only widened and weakened—a sort of partial reversal. What the cause is of the different kinds of chromospheric lines, is a question that with our present lack of knowledge of the conditions in the chromosphere we cannot hope to answer. It is unfortunate that we know so little regarding the conditions which govern the appearance of these lines. While there are numerous investigations of the sun-spot spectrum, and accompanying laboratory investigations to interpret them, the chromosphere has been neglected. The field is a most promising one for investigators, as yet practically untouched with instruments such as are now used in studying the spot spectrum, and one for which photography is well adapted, since the phenomena are usually short lived.

In accordance with the theory of the Zeeman effect, when a source of light in a magnetic field is viewed in a direction along the lines of force the lines of spectrum in general appear double; while when viewed perpendicular to the lines of force the spectrum lines appear triple. The writer's observations at Princeton showed that many doublets were recorded in the spot spectrum, but only a few triplets. In confirmation of these observations Hale has found that certain lines are always doublets in the spot spectrum. Since then King[2] has found that these lines are quadruple in the laboratory when viewed perpendicular to the lines of force, but apparently through the weakening of the central components of the line the light is thrown into maxima at each side, thus giving a doublet, the central line being absent in all cases. In view of the conditions assumed by King[3] in which both triplets and doublets might be seen in neighboring regions of the same spot, the following observations may be of some interest.

[1] *Astrophysical Journal*, **24**, 83, 1906.

[2] *Ibid.*, **29**, 76, 1909.

[3] *Loc. cit.*

The observations were on May 11, 1909, in a spot nearly central on the sun's disk. This spot consisted of one large umbra separated from several smaller ones by a "bridge." At the end of the bridge farthest from the center of the group many lines were recorded triple, while at the other end, near the center of the spot grop, all these lines were double. Other lines, however, appeared double in both regions of the group.

Table II gives the detailed observations of the lines recorded on this date. Columns 1 and 2 are from Rowland and other sources. Columns 3 and 4 give the appearance of the lines in the spectrum of the "outside" and "inside" end of the bridge, respectively.

The table gives only the lines that show evidences of Zeeman effect; all lines otherwise affected have been omitted. Observations in the red end of the spectrum are incomplete owing to the very low altitude of the sun at the time.

By moving the telescope from one region of the spot to the other, the tripled lines could be seen passing through an intermediate stage of hazy widening, resolving finally into the usual doublet as the inside end of the bridge was reached. The lines characterized as "weakened with dark line" were similar to that shown in Fig. 2, p. 79, Vol. **24** of the *Astrophysical Journal*, except that in this case the dark line continued nearly across the spot spectrum. It seems probable that this was in reality a triplet, but there was only lacking sufficient resolving power to show it as such. It is rather curious that nearly half of the above lines have not previously been recorded as doublets in the spot spectrum, while a large proportion of those given in a former table[1] were not seen in this later observation. There is always a chance for error in visual observations, but it seems hardly possible that there could be errors of observation of this magnitude. Fig. 5 (*a*) shows the appearance of the triplets as observed at the "outside" end of the bridge.[2] The central bright strip is the spectrum of the bridge, with the spectra of umbrae on each side of it. The side components of the triple began at the main line as shown, the central line being much stronger than the side lines.

[1] *Astrophysical Journal*, **24**, 85, 1906.

[2] Triplets similar to this were seen in a spot on April 6, 1909; observations on the day before showed the lines weakened with dark line through the center.

TABLE II

Wave-Length	Element	Outside End of Bridge	Inside End of Bridge	Remarks
5131.642	*Fe*	Wide triple	Doublet	
5166.545	*Cr–Fe*	Doublet?	Doublet?	Possibly a very narrow doublet
5192.523	*Fe*	Doublet	Doublet	Hazy and indistinct
5225.695	*Fe*	Strong doublet	Strong doublet	Central portion very bright
5227.043	*Fe–Cr*	Strong doublet	Strong doublet	Slightly hazy
5247.229	*Fe*	Hazy triplet?	Narrow doublet	
5247.737	*Cr*	Hazy triplet	Wide doublet	
5250.385	*Fe*	Wide triplet	Wide doublet	Central line of triplet much stronger than side lines
5261.876	*Ca–Cr*	Hazy triplet?	Narrow doublet	
5275.926	*Cr*	Widened and weakened	Wide hazy doublet	
5298.194	*Cr*	Widened and weakened	Wide hazy doublet	
5300.929	*Cr*	Traces of triplet, hazy and weak	Wide hazy doublet	
5329.329	*Cr*	Traces of triplet, hazy and weak	Wide hazy doublet	
5394.9	*Mn*	Faint traces of triplet	Doublet?	Much widened and darkened over umbra, generally indistinct on bridge
5432.753	*Mn*	Faint traces of triplet	Wide strong doublet	
5433.160	*Fe*	Narrow doublet	Narrow doublet	
5476.778	*Fe*	Hazy	Narrow doublet	
5481.071	*Fe*	Wide doublet	Wide doublet	
5497.735	*Fe*	Hazy doublet?	Hazy doublet?	
5501.683	*Fe*	Hazy doublet	Hazy doublet	
5603.186	*Fe*	Hazy doublet	Hazy doublet	Difficult on account of neighboring lines
5624.769	*Fe, V*	Weakened with dark line	Doublet	
5627.859	*V*	Weakened with dark line	Doublet	Faint on "outside" end
5634.171	*Fe*	Narrow doublet	Narrow doublet	
5638.488	*Fe*	Weakened with dark line	Doublet	
5655.715	*Fe*	Weakened with dark line	Narrow doublet	
5658.097	*V*, —	Hazy triplet	Wide doublet	
5659.052	*Fe*	Doublet	Doublet	Bright center
5662.374	*Ti*	Weakened with dark line	Doublet	
5662.744	*Fe*	Weakened with dark line	Doublet	
5663.155	*Ti,Fe, V*	Weakened with dark line	Doublet	
5667.739	*Fe*	Hazy triplet	Wide doublet	
5705.688	*Fe*	Wide doublet	Wide doublet	
5731.984	*Fe*	Weakened with dark line	Wide doublet	

TABLE II—*Continued*

Wave-Length	Element	Outside End of Bridge	Inside End of Bridge	Remarks
5754.881	*Ni*	Hazy	Doublet	
5774.250	*Ti*	Hazy triplet	Wide doublet	
5781.130	*Cr, Ti*	Faint wide triplet	Faint wide doublet	
5781.400	*Cr*	Faint wide triplet	Faint wide doublet	
5781.967	*Cr*	Faint wide triplet	Faint wide doublet	
5783.288	*Cr*	Wide doublet	Wide doublet	
5784.080	*Cr*	Doublet	Doublet	
5784.879	*Fe*	Doublet	Doublet	
5785.188	*Cr*	Doublet	Doublet	
5785.498	*Fe*	Doublet	Doublet	
5809.439	*Fe*	Weakened with dark line	Narrow doublet	
5916.475	*Fe*	Wide doublet	Wide doublet	
5929.898	*Fe*	Narrow triplet	Wide doublet	
5953.386	*Ti*	Hazy triplet	Narrow hazy doublet	
5983.098	*Fe*	Weakened with dark line	Narrow doublet	
5985.040	*Fe*	Weakened with dark line	Narrow doublet	
5987.290	*Fe*	Weakened with dark line	Narrow doublet	
6003.293	*Fe*	Hazy	Doublet	
6013.715	*Mn*	Hazy	Hazy doublet	
6016.861	*Mn*	Hazy	Doublet	
6022.016	*Mn*	Hazy	Hazy doublet	
6082.930	*Fe*	Wide doublet	Wide doublet	
6102.392	*Fe*	Triplet?	Narrow doublet	
6102.937	*Ca*	Triplet	Strong doublet	
6122.434	*Ca*	Hazy wide doublet	Wide doublet	
6136.829	*Fe*	Hazy	Narrow doublet	
6137.210	*Fe*	Strong triplet	Strong doublet	
6137.915	*Fe*	Hazy	Narrow doublet	
6141.938	*Fe, Ba*	Hazy	Narrow doublet	
6151.834	*Fe*	Triplet	Wide doublet	
6163.968	*Ca*	Doublet	Doublet	
6173.553	*Fe*	Strong wide triplet	Strong wide doublet	
6302.709	*Fe*	Strong triplet	Strong doublet	

The line λ 6173.55 is found by Hale to be a triplet in spots; the writer has found that it is nearly always double in some portion of the region immediately around the spot. In the spectrum of the umbra the line is generally hazy and indistinct, sometimes with indications of tripling. The double appearance is, however, different from that of such lines as λ 5225.6, which are always double; the intensity of the two side components of λ 6173.5 when double is quite small, the line appearing like a triple with the central line removed. The components of the double λ 5225.6, on the other hand are relatively much

stronger. The triple λ 5250.6 is similar to λ 6173.5 in the weakness of the side components; other triples show this also, but the effect is much greater in λ 6173.5.

During the next three days considerable change had taken place in the solar magnetic field, for on May 14 no distinct regions of doubling or tripling could be seen. The strongest action was now confined to a region near the "outside" end of the bridge. The lines at this point appeared as in Fig. 5 (*b*), triple and double in almost the same region. The main line was distinctly weakened below the doublet, becoming strong again a slight distance beyond the penumbral spectrum.

It is to be noted that the triplets and doublets were seen only when the principal umbra was *off* the slit; it is rarely that a distinct doublet or triplet is seen in the spectrum of the umbra itself. This fact has been remarked before. Usually the line is widened and hazy across the umbra and does not resolve itself until some portion of the spot outside the umbra falls on the slit, usually one edge of the penumbra. There seems to be no definite location for the magnetic field which produces the maximum effect, although there are indications that it is more frequently found on the side of the spot nearest to the limb.

By May 17 the spot had become quite close to the limb, while the appearance of the lines had again changed. The triplets had all disappeared, only a few doubles remaining; these were much narrower and, in all cases except λ 5225.6, were hazy and indistinct. Across the spectrum of the bridge the lines were now all much weakened, and slightly displaced toward the blue, the fainter lines being completely obliterated. Even the doublets shared in this weakening and displacement over the bridge, while outside of the spot region the doubling continued for a slight distance. It was interesting to note that the water-vapor lines below D continued unaltered across the spectrum, while the neighboring solar lines were displaced and obliterated. Bright reversals were observed in this region of the spot in many of the chromospheric lines. The principal lines affected were C, D_1 and D_2, λ 5316.790, and b_3, which was particularly brilliant.

Unfortunately, observations cannot be continued at Haverford, as astronomical work at the observatory is to be suspended, but it is hoped that, incomplete as these are, they will be of sufficient interest to afford a reason for publishing them.

HAVERFORD COLLEGE OBSERVATORY
HAVERFORD, PA.
June 1909

A SUMMARY OF THE RESULTS OF A STUDY OF THE MOUNT WILSON PHOTOGRAPHS OF SUN-SPOT SPECTRA[1]

By WALTER S. ADAMS

The investigation of the spectra of sun-spots began at Mount Wilson almost as soon as the Snow telescope was available for use. At first a temporary spectrograph of wood was employed in connection with it, but this was soon replaced by the permanent 18-foot instrument with which practically all of the spectroscopic work on the sun during the years 1906–1907 was carried on. The completion of the tower telescope in the autumn of 1907 proved to be an event of the greatest importance for the future of spectroscopic investigations at the observatory, and the marked improvement in the character of the solar image formed by the telescope, as well as the decided gain in power and efficiency afforded by the 30-foot spectrograph, combined to make great additions to the results of our earlier investigations. In no line of work was this more noticeable than in the study of the spectra of sun-spots.

Our first photographs of the spectra of sun-spots were taken in the ordinary way with a long slit crossing the spot. This, of course, gave a much underexposed spectrum of the spot and we soon adopted the plan of exposing the spot and the comparison spectrum separately by means of a specially constructed occulting bar.[2] A great gain in the amount visible in the spot spectrum resulted from this change. Additional experience in the use of this device, combined with the occurrence of a number of exceptionally large spots during the summer of 1906, enabled us to secure photographs at that time which showed an immense wealth of detail within the spot spectrum. Many results obtained from these plates have since been published.[3] The observa-

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 40.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 5; *Astrophysical Journal*, **23**, 11, 1906.

[3] *Contributions from the Mount Wilson Solar Observatory*, No. 11; *Astrophysical Journal*, **24**, 185, 1906; *Contributions from the Mount Wilson Solar Observatory*, No. 15; *Astrophysical Journal* **25**, 75, 1907.

tions were also extended to the violet part of the spectrum, and by means of specially prepared plates into the red as well. From the series thus obtained a map was prepared by Mr. Ellerman and distributed among those engaged in the study of the spectra of sun-spots. Finally, the use of the tower telescope made possible another great advance in the character of the plates,[1] especially as regards the resolution of close lines; in fact, the plates taken with the tower telescope are in general so much superior to those obtained previously that wherever possible they have been used exclusively for determinations of wave-length and intensity.

In the present paper I wish to summarize some of the principal results of the detailed study of our photographs of sun-spot spectra which has been carried on during the past three years by the aid of the Computing Division in Pasadena. The work has dealt mainly with the identification of the unknown lines present in the spectra of spots, the estimation of the intensities of the lines, measures of width, and, in the case of double and triple lines, of the separation of the components, together with the numerous other details which the investigation of a spectrum so complex as that of a sun-spot necessarily involves. A total of some 11,000 lines has been measured in the spot spectrum and the wave-lengths computed, and in a later extended publication the details of this work will be entered into fully. For the present I wish merely to give in a summarized form some of the principal results found and to call attention to a few of the more interesting applications.

Apart from questions relating to the continuous spectrum of spots, and the position of its maximum of intensity as compared with that of the solar spectrum, the most important characteristics of the sun-spot spectrum may be referred to under three heads.

1. The strengthening and weakening of great numbers of lines, in the case of some elements nearly all the lines being strengthened, in others weakened, while in many other elements both effects are present.

2. The presence in the spot spectrum of an immense number of lines which are not present in the solar spectrum, many of which are grouped in the form of bands and flutings.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 23; *Astrophysical Journal*, **27**, 204, 1908.

3. The widening and, in some cases, doubling and even tripling of numerous lines in the spot spectrum without apparent strengthening.

As the result of solar and laboratory investigations at this observatory, and at the Royal College of Science by Fowler, it now seems probable that all three of these essential features of the sun-spot spectrum have found adequate explanation. The hypothesis presented independently rather more than two years ago by Fowler, on the one hand,[1] and by Hale, Gale, and Adams, on the other,[2] according to which the strengthening and the weakening of lines in the spot spectrum may be accounted for on the basis of reduced temperature in the spot, has found little but confirmatory evidence in the meantime, and it is probably not too much to say that in its essentials, at least, it can hardly be open to serious question. The evidence furnished by the results of the present study will be referred to at a later point in this discussion.

In a note added to the paper already mentioned,[3] reference was made to the discovery of the presence of one of the titanium oxide flutings in sun-spots. As soon as additional plates were available several other flutings were found, and a number of measures were added in a later communication.[4] Since that time the titanium oxide flutings have been investigated extensively at this observatory, and an immense number of identifications made with the unknown lines in the spot spectrum. Shortly after the discovery of these titanium oxide flutings, Fowler announced the identity of some of the prominent spot "bands" in the vicinity of the *b* group of the magnesium lines of the solar spectrum with those due to magnesium hydride. To the same compound he ascribes numerous lines farther to the violet, as well as others in the yellow-green part of the spectrum. In the autumn of 1907 Olmsted found that bands present in the spectrum of the calcium arc burning in an atmosphere of hydrogen were also represented in the spectrum of sun-spots, and a large number of lines have been identified by him in the less refrangible part of the spectrum. It appears probable

[1] *Transactions of the International Union for Coöperation in Solar Research*, 1, 201, 1906.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 11.

[3] *Loc. cit.*, p. 29.

[4] *Contributions from the Mount Wilson Solar Observatory*, No. 15.

from the results of our measurements that the spectra of these three compounds are sufficient to account for the greater part of the unknown lines distributed throughout the spot spectrum.

In regard to the third main feature of spot spectra, the widening and doubling of lines without apparent strengthening, it is only necessary to refer to Mr. Hale's recent important discovery of the Zeeman effect in sun-spots. The products of this research leave little doubt that the Zeeman effect is fully adequate to explain essentially all cases of this sort which have been found in spots.

Plate	Spot	Observer	Region	Measured by
D 7	6609	A.	4000–4550	A.–B.
T 72	6324	H.	4500–4750	B.
T 60	6324	A.	4500–4725	B.
T 67	6324	H.	4500–4775	B.
T 68	6324	H.	4500–4600	B.
			4675–4860	
T 79	6324	A.	4772–4820	B.
			4860–4900	
T (X)			4810–5000	B.
T 47	6318	H.	4870–5000	B.
T (X)			5000–5025	A.
T 76	6324	H.	5000–5500	A.
T 77	6324	H.	5025–5075	A.
T 49	6318	H.	5075–5175	A.
T 61	6324	A.	5175–5500	A.
T 73	6324	H.	5500–5735	A.–B.
T 75	6324	H.	5500–5550	A.
T 154	6511	A.	5720–6250	A.–B.
T 219	6577	H.	6160–6390	A.–B.
T 105	6441	A.	6250–6860	A.–B.–W.
T 102	6393	A.	6500–6925	B.–W.
D 8		A.	6925–7060	B.

The plates upon which the results given in this communication are based, with the exception of two, were selected from the collection of plates taken with the tower telescope, and accordingly represent the best observational material which we have available between the wave-lengths λ 4000 and λ 7000. All the photographs except a few in the extreme red (below λ 6600) have been taken in the third order of the 30-foot spectrograph, and the great linear scale and high resolving power have proved of the greatest possible value in the determinations of wave-lengths and the separation of close neighboring lines. The plates in the extreme red were obtained in the second order. The list of plates used, together with the Greenwich

numbers of the spots, is given below. The initials of the observers and those who have measured the plates are also added. H. refers to Mr. Hale, and A. to myself. Similarly, B refers to Miss Burwell of the Computing Division and W. to Miss Wickham. So far as possible we have made the attempt to have at least two independent determinations of intensities and wave-lengths throughout the entire spectrum. In the case of one plate, T (X), the observational data have unfortunately been lost.

In discussing the results of these plates it seems desirable to consider the features of the spot spectrum under the three heads already referred to, treating the strengthened and weakened lines first, the band and fluting lines next, and finally referring briefly to such lines as are widened or doubled on account of the presence of a magnetic field. In addition to these questions, which will of necessity be discussed in a comparatively brief manner, it will prove of interest to consider more in detail two subjects which arise in the course of the investigation. The first of these is the behavior of the "enhanced" or "spark" lines, understanding by such lines those which are distinctly stronger in the spectrum of the spark than in that of the arc. The second is the behavior of the individual lines of iron throughout the spot spectrum. This element, on account of the great number of its lines and their fairly uniform distribution in the spectrum, as well as the immense variety of appearance and intensity which they present, may probably be considered the most representative element present in the spectrum of spots, and the one from which conclusions in regard to the physical conditions present may most safely be drawn. Accordingly, I wish to give, in addition to the detailed list of the changes in intensity of the principal iron lines between spot and disk, a comparison of the intensities of these same lines in the spectrum of the flame and the core of the electric arc. A partial comparison of this sort from eye estimates of intensity was given in one of the papers already referred to,[1] but the superior material now available and the development of a reasonably accurate quantitative method for the determination of the intensities of the bright lines in laboratory spectra by Mr. Hale and myself make a more complete comparison highly desirable.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 11.

STRENGTHENED AND WEAKENED LINES IN THE SPECTRUM OF SPOTS

Probably the most efficient way of considering the behavior of the strengthened and the weakened lines in a summarized form is by classification in reference to the elements to which they are due. Accordingly, we shall now take up separately the principal elements present in sun-spots, discussing the number of lines strengthened, weakened, and unchanged, and their principal characteristics, referring in detail to lines of particular interest.

CALCIUM

The spectrum of calcium is of marked interest in spots. With the possible exception of one line in the violet, all of the lines given in Rowland's table between λ 4000 and λ 7000, amounting to 60 in number, are strengthened, and in general the amount of the strengthening increases decidedly with the wave-length. Thus for a mean wave-length of 4370 the average of 13 lines gives an amount of increase for the spot intensity over that in the sun of 1.7 on Rowland's scale. An average of 8 lines at λ 5580 in the yellow gives 2.8, while 7 lines in the red at λ 4670 give 4.6. The fact that the solar lines in the yellow and red are stronger than those in the violet part of the spectrum probably affects these results to some extent, but the increase in the amount of change is still noticeable. Thus if we form ratios by dividing the average spot intensities by the average solar intensities for those lines, we find for the three mean wave-lengths the relation 1.5:1.7:1.9. Such a result is to be expected from a shift of the maximum of intensity in the spot spectrum toward longer wave-lengths, if we assume that the same law of intensity holds for line spectra as for continuous spectra. In the case of the hydrogen spectrum Kayser has shown that such an effect does hold.[1]

The behavior of the calcium lines in the spot spectrum is mainly characterized by the great amount of widening and the formation of wings. The latter effect is especially marked for the lines in the less refrangible part of the spectrum, and in some cases these wings reach out on either side of the line to a distance several times its actual width. Conspicuous examples of this sort are λ 6102.94, λ 6122.43,

[1] *Festschrift*, Ludwig Boltzmann (Leipzig), p. 38.

and λ 6162.39, and numerous other lines of less intensity in this region show the effect nearly as well. In fact, it may probably be safely stated that every calcium line to the red of λ 5500 is more or less winged in the spot spectrum, the extent of the wings for lines of equal intensity increasing with the wave-length. There can, I think, be little doubt that these wings are due to the relatively dense vapor lying at a low level in the spots, the light of which is much less scattered and absorbed in the less refrangible part of the spectrum than in the violet, and so is able to penetrate to the observer. Apart from the wings, however, the lines in most cases are decidedly widened and occasionally doubled. The greater part of this effect is no doubt due to the presence of a magnetic field, but the actual increase in the intensities of the lines is almost certainly mainly a temperature condition.

Five lines of calcium deserve individual mention. Of these the H and K lines, while falling outside the limits of the spectrum especially studied in this investigation, have been examined to some extent. As is well known, the central part of both of these lines is always bright over the umbrae of spots. Accordingly, any conclusions about changes of intensity are very difficult. In general there seems to be little change in these lines, although there is a presumption for a slight strengthening of the wings. This is quite in accord with what is true of the entire spot spectrum in the violet region, the changes of intensity being comparatively few in number and small in amount where they do occur. Like H and K, the "blue" line of calcium at λ 4227 is not very greatly affected, although it is unmistakably strengthened and its wings considerably increased in extent. The fact that this line lies in the violet part of the spectrum is no doubt accountable for the comparatively small change of its intensity in spots.

The other two lines to which I wish especially to refer are λ 6573.03 and λ 6708.08. The first is identified by Rowland as probably due to calcium, and both lines were shown by Mr. Hale and myself to be immensely strengthened in the flame of the arc as compared with the core. The first line is one of the most strongly affected lines in the entire spot spectrum, showing a rise of intensity from 1 in the sun to 10 in the spot. It is still somewhat doubtful whether the second line is due to calcium or to an impurity, possibly lithium, which has a

strong line close to this point. Moreover, the existence of this line in the solar spectrum is made rather questionable by our latest determinations of the wave-length of the sun-spot line, which give for it λ 6708.08. The nearest line in Rowland's table to this is λ 6708.18, which leaves a large discrepancy. The line, however, has an intensity of about 5 in spots and is noticeably unsymmetrical. It may well happen, accordingly, that the solar line is blended with one or more of the band and fluting lines which abound in this region, and that the difference of wave-length is due to this cause.

CHROMIUM

The lines of chromium exhibit the same great variety of behavior in spots as do the lines of iron, although the proportion of strengthened lines is considerably greater. Our tables contain a total of 342 lines due to this element which are affected in sun-spots. Of these 200 are strengthened, 36 (including the "enhanced" lines) weakened, while the remaining lines are either of doubtful origin or occur as blends on our plates. The percentage of lines affected to the total number of chromium lines in Rowland's table between the wave-lengths considered is about 88. In general the lines of chromium which are strengthened in sun-spots agree closely with those which are strengthened in the flame of the arc, and, in fact, chromium and iron furnish the most valuable part of the evidence upon which the hypothesis of a lower temperature in spots is based. Among the numerous cases of lines which are greatly strengthened in both the flame of the arc and the spot spectrum we may call attention to λ 5298.455, λ 5345.991, and λ 5410.000.

The group of lines beginning at about λ 5780 is deserving of special note, as indicating the great value of the high dispersion of the tower telescope plates in discussing the question of intensity. On the earlier plates taken with the Snow telescope and the 18-foot spectrograph several of the lines in this group were found to be greatly widened and for this reason their intensities were probably assigned too high a value. As a result the amount of strengthening in the flame of the arc for these lines was relatively too small, and they appeared exceptional in their behavior. The later plates taken with the tower telescope show that these greatly widened lines are in reality doublets,

due to the presence of a magnetic field in spots. Accordingly, it became possible to determine the intensities of the components separately, and it was then found that the behavior of the lines was much more nearly in agreement with the laboratory results.

COBALT

From a total of 118 lines of cobalt given in Rowland's table, 82, or 69 per cent., occur in our sun-spot tables as affected. Of these, however, 39, or nearly half, occur as blends or compound lines. Of the lines due to cobalt alone, 26 are strengthened and 17 weakened, and for the blended or compound lines about the same proportion holds.

As a rule the cobalt lines which show strengthening are not greatly affected, the amount of increase in intensity rarely amounting to 1 on Rowland's scale. In almost all cases they are considerably widened, and in this respect their behavior is very similar to that which they show at the limb of the sun, where the effect on the lines due to this element is very marked. Several of the fainter cobalt lines, particularly in the green and yellow region of the spectrum, are obliterated, and numerous others much weakened. This fact is of especial interest on account of the prominence of the cobalt lines in this region in the spectrum of the chromosphere. Some recent observations by myself with the tower telescope indicate that practically all of the cobalt lines in the less refrangible part of the spectrum, including numerous lines not given by Rowland but identified with solar lines by the aid of Hasselberg's arc tables, appear as bright lines in the chromosphere. An examination of these lines in the spot spectrum shows that in a majority of cases they are weakened and in all other cases unchanged in intensity, while no lines are strengthened. The behavior of the cobalt lines at the sun's limb and in the chromosphere indicates that special significance must be attached to this element in discussions of the constitution of the solar atmosphere.

HYDROGEN

The four lines of hydrogen which occur in the region of the spectrum under investigation are all weakened in the spectrum of sun-spots. There are, however, probably no lines in the spot spectrum so subject to large variations of intensity depending upon the character of the

photographs. Thus some of our best negatives show $H\delta$ obliterated in the spot spectrum, while others, apparently little inferior, give it an intensity of 5 to 10 on Rowland's scale. There is some evidence to indicate that the hydrogen lines are most weakened in spots in which the bands and flutings are especially strong. If such is the case, it would tend to show that a large part of the hydrogen in spots goes to the formation of the hydride compounds, thus producing weakening of the hydrogen lines, but the evidence is as yet insufficient. Our best observational material gives the following intensities for the four lines:

Line	Intensity in Sun	Intensity in Spot
$H\delta$.....	40 N	1
$H\gamma$.....	20 N	4
$H\beta$.....	30	10
$H\alpha$.....	40	25

The relative increase of intensity of the spot lines toward longer wave-lengths is very noticeable and is the more remarkable, as we should expect some tendency toward reversion to the intensities of the ordinary solar spectrum in the violet region. As it is, their behavior indicates a marked shift of the maximum intensity in the spectrum toward longer wave-lengths, which in accordance with Kayser's observations of the hydrogen spectrum[1] indicates a reduction of temperature. This independent evidence in favor of low temperature in spots is of considerable value.

IRON

The number of lines ascribed to iron in Rowland's table, between λ 4000 and λ 7000, is 1108. Of these 784, or 71 per cent., appear in our spot lists as affected, 558 being lines due to iron alone and the remainder to two or more elements or to blends. The doubtful cases amount to 40, or about 7 per cent. of the lines affected. Of the 558 lines due to iron alone 300 are strengthened and 258 weakened, with approximately the same relation holding for the compound and the blended lines. The number of lines weakened is naturally much

[1] *Festschrift*, Ludwig Boltzmann (Leipzig), p. 38.

increased by the "enhanced" lines, of which there are many in the spectrum of this element.

The lines of iron exhibit almost every conceivable type of behavior in spots. With the exception of calcium and sodium, its lines are more frequently winged than those of any other element occurring in spots, the effect in general increasing with the wave-length, as in the case of calcium. The strengthened lines are sometimes much widened, at other times of about their normal width, the centers of the lines being darkened and the form of intensity curve considerably modified. The question of width is of course greatly complicated by the presence of the Zeeman effect, but with the aid of laboratory plates due allowance can be made for this. A similar variety of behavior is found among the weakened lines, many of the "enhanced" lines being especially narrow in spots.

In view of the importance of the spectrum of iron it seems desirable to give the results for the more prominent of its lines in greater detail, and, at the same time, to indicate the nature of the evidence furnished by them regarding the question of the temperature in sun-spots. Accordingly, in a table which follows is given a list of all the iron lines which are sufficiently strong upon our laboratory plates for purposes of estimation of intensity. The behavior of these lines in spots is then shown, and in the last columns of the table a comparison of the intensities of these lines in the core and in the outer flame of the electric arc is added. The latter are from two plates of the iron spectrum kindly obtained for me by Mr. Olmsted.

The method by which the intensities of the lines upon the laboratory plates were obtained needs a few words of explanation. At the time of the publication of the earlier papers on the spectra of sun-spots by Mr. Hale and myself the necessity for some more satisfactory method of obtaining the intensities of bright lines was felt strongly, and a considerable number of experiments were made with the aid of a Hartmann photometer. The process of securing determinations of intensity with such an instrument, however, proved comparatively slow and the results obtained were unnecessarily accurate for purposes of comparison with sun-spot lines. The use of a scale of standard lines was then suggested by Mr. Hale as a rapid and sufficiently accurate means of obtaining intensities. After some trials with different

light-sources it occurred to me that the direct reflection from a grating surface might be utilized. A photograph made, using an incandescent lamp and exposure times varying in definite ratio, proved satisfactory for the purpose in mind. As soon as such a scale was available it became possible by the aid of the Hartmann spectro-comparator to carry out the rapid and simple comparisons of the lines on laboratory plates with the lines in the standard scale, by matching the lines in the two cases until equality was obtained. This method for the determination of intensities was later given by us to Mr. King and used by him in his investigation of intensities of lines in the electric furnace.

The standard scale employed in obtaining values found in the table below was secured by photographing the direct reflection in the 18-foot spectrograph of light from the northern sky thrown upon the slit by the Snow telescope. The series of exposures covered so short a time that change of illumination could have had little appreciable effect. The exposure times were varied from 1 to 128, but the actual range used in the determinations, with the exception of two or three lines, was from 3 to 40. It seems probable from measures of the widths of lines taken with different exposure times that within these limits the reciprocity law holds with fully as high a degree of accuracy as is needed for the purpose of comparison with the eye estimates of the intensities of the sun-spot lines.

I am indebted to Miss Wickham for the determination of the intensities of the arc lines. The values for the spot lines are the means of estimates by Miss Burwell and myself. In the case of one of the laboratory plates the intensities in the flame have been multiplied by a constant factor in order to make the general strength of the spectrum comparable with that of the core of the arc. With this exception the values given are such as were found independently for the laboratory and for the sun-spot plates. In the two columns preceding the last are given the ratios $\frac{\text{Sun intensity}}{\text{Spot intensity}}$ and $\frac{\text{Core intensity}}{\text{Flame intensity}}$. The agreement of these ratios is of course the test of whether the change of intensities found in passing from the disk of the sun to a spot is similar to that found in passing from the core to the flame of an electric arc. The last column gives the differences of the two ratios.

λ	Substance	Intensity		Intensity		Spot Ratio	Arc Ratio	Δ
		Sun	Spot	Flame	Core			
4005.408	*Fe*	7	n. c.	24	18	1.0	0.8	+0.2
4030.646	*Nd–Fe–Ti*	5	6	28	18	0.8	0.6	+0.2
4033.224	*Mn*	8d?	10	26	16	0.8	0.6	+0.2
4033.337	*Fe?*	1						
4034.533	—	1	7	22	15	0.9	0.7	+0.2
4034.644	*Mn–Fe*	6d						
4045.975	*Fe*	30	n. c.	34	33	1.0	1.0	0.0
4063.759	*Fe*	20	n. c.	32	32	1.0	1.0	0.0
4071.908	*Fe*	15	n. c.	30	28	1.0	1.0	0.0
4118.708	*Fe*	5	4	12	16	1.2	1.4	−0.2
4127.767	*Fe*	4	3	8	13	1.0	1.6	−0.6
4134.840	*Fe*	5	n. c.	12	18	1.0	1.5	−0.5
4144.572	*Fe*	4	3	16	36	1.3	2.2	−0.9
4144.038	*Fe*	15	n. c.	30	36	1.0	1.2	−0.2
4147.836	*Fe*	4	5	12	12	0.8	1.0	−0.2
4181.919	*Fe*	5	n. c.	16	20	1.0	1.2	−0.2
4185.058	*Fe, Cr*	4	n. c.	8	13	1.0	1.6	−0.6
4187.943	*Fe*	5	n. c.	20	22	1.0	1.1	−0.1
4188.019	—	3						
4191.595	*Fe*	6	7	16	20	0.9	1.2	−0.3
4198.402	—	4	n. c.	20	26	1.0	1.3	−0.3
4198.494	*Fe*	4						
4199.267	*Zr–Fe*	5	4	18	24	1.2	1.4	−0.2
4202.198	*Fe*	8	n. c.	28	29	1.0	1.0	0.0
4210.494	*Fe*	4	6	12	17	1.2	1.4	−0.2
4210.561	—	3						
4219.516	*Fe*	4	n. c.	24	18	1.0	0.8	+0.2
4219.580	—	3						
4222.382	*Fe*	5	6	14	16	0.8	1.2	−0.4
4224.337	*Fe*	4	5	14	14	0.8	1.0	−0.2
4227.606	*Fe*	4	n. c.	18	26	1.0	1.4	−0.4
4233.772	*Fe*	6	7	18	24	0.9	1.4	−0.5
4236.112	*Fe*	8	n. c.	22	26	1.0	1.2	−0.2
4247.591	*Fe*	4	3	10	17	1.3	1.7	−0.4
4250.287	*Fe*	8	7	20	28	1.1	1.4	−0.3
4250.945	*Fe*	8	n. c.	32	24	1.0	0.8	+0.2
4260.640	*Fe*	10	8	28	36	1.2	1.3	−0.1
4271.325	*Fe*	6	5	24	12	1.2	1.6	−0.4
4271.934	*Fe*	15	13	40	40	1.1	1.0	+0.1
4282.565	*Fe*	5	n. c.	20	18	1.0	0.9	+0.1
4291.630	*Fe*	2	3	16	8	1.7	0.5	+0.3
4294.204	*Ti*	2	8	30	27	0.9	0.9	0.0
4294.301	*Fe*	5						
4308.081	*Fe, Ti*	6	8	36	33	0.8	0.9	−0.1
4315.262	*Fe*	4	5	20	18	0.8	0.9	−0.1
4325.939	*Fe*	8	7	40	48	1.1	1.2	−0.1
4337.216	*Fe*	5	6	22	18	0.8	0.8	0.0
4352.908	*Fe*	4	5	18	16	0.8	0.9	−0.1
4367.749	*Fe*	5	4	12	12	1.2	1.0	+0.2
4376.107	*Fe*	6	8	32	18	0.8	0.6	+0.2
4383.720	*Fe*	15	n. c.	72	72	1.0	1.0	0.0
4389.413	*Fe–*	2	3	14	13	0.7	1.0	−0.3
4404.927	*Fe*	10	9	52	36	1.1	0.7	+0.4
4415.293	*Fe*	8	n. c.	48	31	1.0	0.7	−0.3

λ	Substance	Intensity		Intensity		Spot Ratio	Arc Ratio	Δ
		Sun	Spot	Flame	Core			
4427.482	*Fe*	5	7	36	20	0.7	0.6	+0.1
4430.785	*Fe*	3	4	14	14	0.8	1.0	−0.2
4433.390	*Fe*	3	n. c.	16	10	1.0	0.6	+0.4
4442.510	*Fe*	6	7	20	18	0.9	0.9	0.0
4443.365	*Fe*	3	n. c.	12	15	1.0	1.2	−0.2
4447.892	*Fe*	6	7	20	18	0.9	0.9	0.0
4454.552	*Fe*	3	4	12	13	0.8	1.1	−0.3
4459.199	*Ni*	2	7	20	17	0.7	0.8	−0.1
4459.301	*Fe*	3						
4461.818	*Fe*	4	7	40	19	0.6	0.5	+0.1
4466.727	*Fe*	5	7	20	19	0.7	0.9	−0.2
4476.185	*Fe*	4	8	20	19	0.9	1.0	−0.1
4476.253	*Ag*	3						
4482.338	*Fe*,–	5	11	36	20	0.7	0.6	+0.1
4482.438	*Fe*	3						
4489.911	*Fe*	4	6	24	12	0.7	0.5	+0.2
4494.738	*Fe*	6	8	24	20	0.8	0.8	0.0
4525.314	*Fe*	5	6	18	13	0.8	0.7	+0.1
4528.647	*V*	0N	n. c.	30	26	1.0	0.8	+0.2
4528.798	*Fe*	8						
4531.327	*Fe*	5	7	24	16	0.7	0.7	+0.1
4592.840	*Fe*	4	5	20	13	0.8	0.7	+0.1
4603.126	*Fe*	6	7	24	18	0.9	0.8	+0.1
4647.617	*Fe*	4	5	14	13	0.8	1.0	−0.2
4654.672	*Fe*	4	9	16	17	0.9	1.0	−0.1
4654.800	*Fe*	5						
4733.779	*Fe*	4	6	12	11	0.7	0.9	−0.2
4736.963	*Fe*	6	6	18	17	0.9	1.0	−0.1
4787.003	*Fe*	2	n. c.	14	10	1.0	0.7	+0.3
4789.849	*Fe*	3	2.5	8	11	1.2	1.4	−0.2
4859.928	*Fe*	4	7	20	18	0.6	0.9	−0.3
4871.512	*Fe*	5	n. c.	24	30	1.0	1.2	−0.2
4872.332	*Fe*	4	n. c.	18	23	1.0	1.3	−0.3
4890.948	*Fe*	6	n. c.	22	32	1.0	1.4	−0.4
4891.683	*Fe*	8	6	28	32	1.3	1.3	0.0
4903.440	*Cr*	0	7	16	16	0.8	1.0	−0.2
4903.502	*Fe*	5						
4919.174	*Fe*	6	n. c.	24	32	1.0	1.3	−0.3
4920.685	*Fe*	10	n. c.	36	32	1.0	0.8	+0.2
4938.997	*Fe*	4	n. c.	12	13	1.0	1.1	−0.1
4939.868	*Fe*	3	5	18	10	0.6	0.6	0.0
4957.480	*Fe*	5	n. c.	48	54	1.0	1.1	−0.1
4957.785	*Fe*	8						
4966.270	*Fe*	4	5	10	11	0.8	1.1	−0.3
4982.682	*Fe*	4	3	6	12	1.3	2.0	−0.7
4985.432	*Fe*	3	n. c.	10	12	1.0	1.2	−0.2
4994.316	*Fe*	3	5	11	11	0.6	0.5	+0.1
5002.044	*Fe*	5	4	10	14	1.2	1.4	−0.2
5005.896	*Fe*	4	n. c.	18	20	1.0	1.1	−0.1
5012.252	*Fe*	4	7	32	18	0.7	0.6	+0.1
5012.335	–	1						
5041.069	*Fe*	3d?	9	18	12	0.8	0.6	+0.2
5041.255	*Fe*	4						
5041.936	*Fe*	4	6	20	15	0.7	0.7	0.0

λ	Substance	Intensity		Intensity		Spot Ratio	Arc Ratio	Δ
		Sun	Spot	Flame	Core			
5050.008	*Fe*	6	8	18	16	0.8	0.9	−0.1
5051.825	*Fe*	4	7	26	14	0.6	0.6	0.0
5068.944	*Fe*	5	6	12	12	0.8	1.0	−0.2
5074.932	*Fe*	5	4	6	10	1.2	1.6	−0.4
5079.921	*Fe*	4	7	16	8	0.6	0.5	+0.1
5083.518	*Fe*	4	6	22	12	0.7	0.6	+0.1
5098.885	*Fe*	3	5	14	11	0.6	0.8	−0.2
5107.619	*Fe*	4	12	24	16	0.7	0.6	+0.1
5107.823	*Fe*	4						
5110.574	*Fe*	5d	8	36	14	0.6	0.4	+0.2
5123.899	*Fe*	3	n. c.	20	22	1.0	0.6	+0.4
5127.533	*Fe, Ti*	3	6	18	9	0.5	0.5	0.0
5133.870	*Fe*	4	n. c.	8	16	1.0	2.0	−1.0
5139.427	*Fe*	4	n. c.	24	35	1.0	1.4	−0.5
5139.644	*Fe*	4						
5142.693	*Fe*	4d?	5	20	12	0.8	0.6	+0.2
5151.020	*Fe*	4	6	20	10	0.7	0.5	+0.2
5153.414	*Fe*	1	2	16	7	0.5	0.5	0.0
5162.449	*Fe, C*	5	n. c.	6	13	1.0	2.2	−1.2
5167.678	*Fe*	5	6	76	40	0.8	0.6	+0.2
5169.069	*Fe*	3	6	30	24	0.5	0.4	+0.1
5171.778	*Fe*	6	8	34	26	0.8	0.8	0.0
5191.629	*Fe*	4	5	20	28	0.8	1.4	−0.6
5192.523	*Fe*	5	n. c.	24	39	1.0	1.6	−0.6
5195.113	*Fe*	4	6	26	20	0.7	0.8	−0.1
5198.888	*Fe*	3	5	12	8	0.6	0.6	0.0
5202.516	*Fe*	4	n. c.	16	14	1.0	0.9	+0.1
5204.680	*Cr*	5	5	24	7	0.6	0.3	+0.3
5204.768	*Fe*	3						
5208.776	*Fe*	2	n. c.	10	12	1.0	1.2	−0.2
5215.353	*Fe*	3	4	6	11	0.8	1.8	−1.0
5216.437	*Fe*	3	5	22	16	0.6	0.8	−0.2
5217.552	*Fe*	3	n. c.	4	9	1.0	2.2	−1.2
5227.362	*Fe*	5d?	7	52	44	0.7	0.8	−0.1
5233.122	*Fe*	7	9	28	32	0.8	1.1	−0.3
5242.658	*Fe*	2	3	16	7	0.7	0.5	+0.2
5250.817	*Fe*	3	4	18	10	0.8	0.6	+0.2
5263.486	*Fe*	4	n. c.	12	11	1.0	0.9	+0.1
5266.738	*Fe*	6	9	24	24	0.7	1.0	−0.3
5269.723	*Fe*	8d?	11	80	40	0.7	0.5	+0.2
5270.558	*Fe*	4	5	36	36	0.8	1.0	−0.2
5273.339	*Fe*	3	4	20	11	0.8	0.6	+0.2
5281.971	*Fe*	5	7	16	16	0.7	1.0	−0.3
5283.802	*Fe*	6	9	20	18	0.7	0.9	−0.2
5302.480	*Fe*	5	7	18	12	0.7	0.6	+0.1
5307.541	*Fe*	3	5	16	3	0.6	0.2	+0.4
5324.373	*Fe*	7	8	26	32	0.9	1.2	−0.3
5328.236	*Fe*	8d?	11	100	68	0.7	0.7	0.0
5333.089	*Fe*	4	7	16	7	0.6	0.5	+0.1
5340.121	*Fe*	6	n. c.	16	16	1.0	1.0	0.0
5341.213	*Fe*	7	10	32	20	0.8	0.6	+0.2
5341.337	*Mn*	1						
5371.656	*Cr?*	4	7	80	40	0.6	0.5	+0.1
5371.734	*Fe*	3						

λ	Substance	Intensity		Intensity		Spot Ratio	Arc Ratio	Δ
		Sun	Spot	Flame	Core			
5383.578	*Fe*	6	n. c.	20	20	1.0	1.0	0.0
5397.344	*Fe*	7d?	12	72	36	0.6	0.5	+0.1
5404.357	*Fe*	5	n. c.	22	22	1.0	1.0	0.0
5405.989	*Fe*	6	10	80	40	0.6	0.5	+0.1
5411.124	*Fe*	4	n. c.	20	13	1.0	0.7	+0.3
5415.416	*Fe–V*	5	n. c.	22	28	1.0	1.2	−0.2
5424.290	*Fe*	6	n. c.	24	28	1.0	1.2	−0.2
5429.911	*Fe*	6d?	11	80	40	0.5	0.5	0.0
5434.740	*Fe*	5	7	52	36	0.7	0.7	0.0
5445.259	*Fe*	4	6	20	11	0.7	0.6	+0.1
5447.130	*Fe*	6d?	11	64	40	0.5	0.6	−0.1
5455.834	*Fe*	4	10	64	40	0.4	0.6	−0.2
5463.174	*Fe*	3						
5463.318	—	0000	7	20	24	0.9	0.6	+0.3
5463.494	*Fe*	3						
5476.778	*Fe*	3	n. c.	16	10	1.0	0.6	+0.4
5497.735	*Fe*	5	11	28	16	0.5	0.5	0.0
5501.685	*Fe*	5	11	26	12	0.5	0.5	0.0
5507.000	*Fe*	5	10	32	15	0.5	0.5	0.0
5569.848	*Fe*	6	n. c.	14	16	1.0	1.1	−0.1
5573.075	*Fe*	6	7	16	20	0.9	1.2	−0.3
5586.991	*Fe*	7	n. c.	16	20	1.0	1.2	−0.2
5615.877	*Fe*	6	n. c.	18	24	1.0	1.3	−0.3
6020.401	*Fe*	4	n. c.	13	12	1.0	0.9	+0.1
6024.281	*Fe*	7	n. c.	13	13	1.0	1.0	0.0
6065.709	*Fe*	7	8	14	14	0.9	1.0	−0.1
6136.829	*Fe*	8	9	15	16	0.9	1.0	−0.1
6137.915	*Fe*	7	8	12	14	0.9	1.2	−0.3
6191.779	*Fe*	9	10	13	15	0.9	1.1	−0.2
6246.535	*Fe*	8	n. c.	14	9	1.0	0.6	+0.4
6252.773	*Fe*	7	9	13	13	0.8	1.0	−0.2
6301.718	*Fe*	7	8	13	9	0.9	0.7	+0.2
6393.820	*Fe*	7	9	13	11	0.8	0.8	0.0
6400.217	*Fe*	8	9	14	13	0.9	0.9	0.0
6411.865	*Fe*	7	10	11	8	0.7	0.7	0.0
6421.570	*Fe*	7	11	12	6	0.6	0.5	+0.1
6431.066	*Fe*	5	9	12	7	0.6	0.5	+0.1
6495.213	*Fe*	8	9	14	13	0.9	0.9	0.0

Several important considerations should be borne in mind in discussing these results. The first is the influence of the widening of the lines in the spot spectrum upon estimates of intensity. The plan we have followed has been to estimate the intensity of a spectrum line as the product of its blackness by its width. Since the great majority of spot lines are widened, owing to the presence of a magnetic field, this has involved the comparison of lines in spot and disk which differ widely in appearance, the sun-spot lines sometimes reaching a width two or three times as great as the corresponding lines in the solar

spectrum. This cause has made accurate estimates very difficult and has undoubtedly increased the error in proportion. In general the effect is in the direction of assigning too high values to the intensities of the spot lines, since to the eye the blackness rarely seems to decrease in proportion to the widening. To this is probably due, at least in part, the fact that in the table the largest discrepancies between spot and flame intensities are always negative. Thus the spot intensities are relatively too high.

A second consideration is that the absolute temperatures of the sources between which comparison is being made are widely different. The temperature of the sun's disk is of course much higher than that of the electric arc, and it is probable that the temperature of the spot is above that of the outer parts of the flame of the arc, although perhaps not greatly so. In regard to the latter question we are able to state that the temperature in spots must be sufficiently low for the existence of titanium oxide and the two hydride compounds known to be present, and, at the same time, sufficiently high to vaporize titanium and vanadium. It seems probable, accordingly, that there is a considerably greater difference of temperature between disk and spot than between the central and the outer portions of the arc, and hence we might readily expect marked differences in the relative behavior of the individual lines.

Still another point to be considered is that in the solar photographs we are never dealing with the pure spot spectrum, since there is always present light from the sky and from the solar photosphere. The effect of this superposed spectrum can easily be seen. If we imagine two spectra of a sun-spot, one without the presence of any extraneous light and the other such as is actually obtained in practice, it is evident that for equal intensities of the continuous spectrum the intensities of the lines in the second spectrum will be too high for the weakened lines and too low for the strengthened lines. The effect on the weakened lines will probably be considerably the greater when visual estimates of intensity are made, and this may also be partially accountable for the fact that in the case of the largest discrepancies found in the table the spot lines are relatively too strong.

A general comparison of the results given in the table may be best obtained by forming the means of the differences over a con-

siderable range of wave-length, thus partially eliminating the effects of accidental errors. If we take intervals of 250 Ångström units and form the differences $\frac{\text{Sun intensity}}{\text{Spot intensity}} - \frac{\text{Core intensity}}{\text{Flame intensity}}$, both with and without regard to sign, we obtain the following table:

Mean λ	No. Lines	Δ (Without Sign)	Δ (With Sign)
4125	28	0.27	−0.20
4375	33	0.16	0.00
4625	9	0.12	−0.01
4875	17	0.24	−0.15
5125	38	0.28	−0.15
5375	31	0.15	+0.03
5625	6	0.15	−0.15
6125	7	0.17	−0.03
6375	8	0.08	+0.02
	177	0.20	−0.11

The large residuals in this table at λ 4125, λ 4875, and λ 5125 are greatly affected by the inclusion of a few lines which show large negative discrepancies. If, for example, we omit three lines at λ 4125, two lines at λ 4875, and four lines at λ 5125, we obtain:

λ	No. Lines	Δ (Without Sign)	Δ (With Sign)
4125	25	0.22	−0.14
4875	15	0.20	−0.09
5125	34	0.17	−0.03

I have already referred to some reasons why we should expect the largest residuals to be negative. In addition there can be little doubt that the difference in the violet at λ 4125 is mainly due to the fact that the effect of the overlying solar spectrum is strongest in this region and has a tendency to give too high intensities for all the weakened lines.

The average deviation for all of the lines in the table taken regardless of sign is 0.20, or, including sign, −0.11. If we omit ten of the lines which show especially large negative discrepancies, we obtain 0.17 taken regardless of sign, and −0.03 taken with regard to sign. These values may, I think, be considered quite satisfactory in view of the difficulties entering into such a comparison, and the inherent differences between the sources compared. The evidence

afforded by the yellow and red portion of the spectrum is especially important, since changes of intensity both in spot and in flame are greatest here, and the disturbing effect of the overlying solar spectrum is relatively less. An inspection of the table shows that it is in this region that the agreement is best, the average deviation for the 44 lines to the red of λ 5300 amounting to less than 0.13 taken regardless of sign. Among the especially important individual lines in the yellow we may call attention to λ 5397.344, λ 5405.989, λ 5429.911, and λ 5447.130, which are greatly strengthened in both spot and flame of the arc; and to the lines of about the same average intensity, λ 5383.578, λ 5404.357, λ 5415.416, λ 5434.740, which are not affected in sun-spots, and either unaffected or slightly weakened in the flame. The evidence afforded by such lines is very important.

In conclusion I think it may be said that this quantitative examination of the arc lines of iron furnishes strong evidence that the changes of intensities of spectrum lines found in passing from the solar disk to a sun-spot are very similar to those found in passing from the center to the outer portions of the electric arc. As regards the question whether temperature is the primary factor in producing these changes, the arguments advanced in the earlier papers by Mr. Hale and myself remain essentially unchanged, and the discovery since that time of the presence of two hydride compounds in the spot spectrum has certainly furnished strong direct evidence for low temperature in sun-spots. In this respect I wish to express my full agreement with Mr. Evershed in his discussion with Professor Whittaker[1] regarding the possibility of the origin of these bands through increased pressure in the spot. In the course of an investigation of the displacements at the sun's limb I have made many attempts to detect pressure-shifts in sun-spots, using for the purpose the lines which show the largest shifts in the laboratory. With a single exception all of these attempts have given negative results. Since a shift of 0.003 or 0.004 Ångström could be detected with the dispersion employed, the excess of pressure in spots over that on the surface of the sun can hardly be as much as one atmosphere. In the case of one spot a value of 0.008 Ångström was obtained. It seems altogether improbable that such a relatively small increase of pres-

[1] *The Observatory*, **31**, 372–374, 462–464, October and December 1908.

sure could bring out in such a remarkable manner the band and fluting lines found in spots. In fact, some investigations made at Mount Wilson with a rotating arc in a pressure-chamber show that this almost certainly cannot be the case for titanium.

MAGNESIUM

The magnesium lines in general show little change in the spot spectrum. Our lists give, out of a total of 8 lines, 3 lines strengthened, 1 weakened, and 4 unchanged. The weakened line is the one farthest to the violet at λ 4352.083, and the effect is very slight. In the *b* group the averages taken from our tables give a small amount of strengthening for b_2 and b_4 and no change for b_1. The conclusion is that the entire group is scarcely affected in sun-spots. The only magnesium line which shows any marked change is λ 4571.275, which is increased from 5 in the sun to 7 in the spot, according to the mean of the observations.

MANGANESE

The percentage of manganese lines affected in spots is about the same as that for cobalt and iron, 123 lines out of a total of 167, or 74 per cent., appearing in our lists. Of the lines due to manganese alone, 68 are strengthened and 15 weakened, the remaining 40 lines being due to two or more elements or being blends. The greater part of the weakened lines fall in the violet portion of the spectrum and the majority of these are "enhanced" lines.

The most interesting lines of manganese fall in the green and yellow portion of the spectrum. Many of the lines in this region are much strengthened in spots and usually greatly widened as well. Such lines as a rule are extremely hazy, and were it not for this diffuseness would probably be readily separable into doublets or triplets. As it is, there are comparatively few measurable doublets in the spot spectrum of this element. Investigations with the flame and core of the arc and with an electric furnace indicate that the lines of manganese are especially sensitive to changes of temperature. This fact has made them of great value in testing the hypothesis of a reduction of temperature in sun-spots as the means of accounting for their spectra, and the agreement has been found to be excellent.

NICKEL

Nickel shows an exceptionally large number of weakened lines in the spectrum of sun-spots, the proportion being greater than for any element investigated except silicon. Thus out of a total of 154 lines due to this element alone, which are affected in spots, 106, or 69 per cent., are weakened. In general, the amount of strengthening or weakening in the case of nickel is comparatively small, its spectrum being similar to that of cobalt in this respect. The ratio of the total number of lines of nickel affected to the number appearing in Rowland's table, including lines of compound origin, is as 204 to 251, or about 80 per cent. This is considerably greater than in the case of cobalt, and is evidently due to the much larger number of weakened lines.

SCANDIUM

The three elements, scandium, titanium, and vanadium, behave very much alike in the spot spectrum. With the exception of the "enhanced" lines, almost all the lines in the spectrum of these substances are strengthened, the amount of strengthening increasing rapidly toward longer wave-lengths. Rowland has identified comparatively few lines in his table with scandium, but by the aid of Lockyer and Baxandall's[1] recent complete investigation of its arc spectrum it is possible to supplement the list considerably.

Out of a total of 45 lines which we have identified with reasonable probability as due to scandium, 33 are affected in sun-spots, while the remaining 12 show no change. Of these 12 all but 3 occur to the violet of λ 4500, where the effect would naturally be comparatively small. Among the lines which are affected 30 are strengthened and 3 weakened, and it seems fairly probable that the latter are either enhanced lines or due to more than a single element. Their wave-lengths are 4276.996, 4314.248, and 5031.199. The first of these is one of the strongest lines in the entire scandium spectrum: it was originally assigned by Rowland to yttrium and later changed to scandium. In connection with their investigation of the spectrum of scandium, Lockyer and Baxandall have published a list of 8 chromospheric lines which they have assigned to this element. A

[1] *Monthly Notices*, **65**, 16, 1905.

comparison of the behavior of these lines in spots is of interest. One line in the list, λ 4399.935, is omitted, since a strong enhanced line of titanium coincides with it.

λ	Intensity in Sun	Intensity in Spot	Arc Max. = 10	Spark Max. = 10
4246.996	5	3	10	10
4314.248	3	2	9	8
4320.907	3	3	9	6
4374.628	3	3	8	6
4670.590	2	2	7	4
5031.199	3	1	8	3
5527.033	3	3	10	7

While the values given do not indicate that any of these lines are enhanced in the spark, it seems fairly probable that some of them are affected in this way, since the spark intensities as given seem to be weaker than those in the arc. In any case it is interesting to note that all three of the scandium lines which are weakened in spots appear in this list as chromospheric lines, and that of the other lines none is strengthened. This comparison shows that, as in the case of other elements investigated, lines present in the chromosphere are usually weakened in spots.

Some of the lines of scandium in the yellow are strengthened more in proportion to their solar intensities than the lines of any other element in the spectrum except vanadium and titanium. Among the most prominent cases of this sort are λ 5482.200, which rises from oooo to 4; λ 5672.047, from o to 3; λ 5687.063, from ooo to 4; and λ 5700.402, from oo to 3. The line λ 5711.98, which seems to have no corresponding line in the solar spectrum, appears in spots with an intensity of 3.

SILICON

All of the lines of silicon which appear in Rowland's table, nine in number, are much weakened in spots. The list on the following page indicates their behavior.

It seems probable that this weakening of the silicon lines is due to the relatively low temperature in spots, since experiments with an electric arc fed with metallic silicon indicate a marked weakening of the lines in the outer portions of the flame as compared with the center of the arc.

λ	Element	Intensity in Sun	Intensity in Spot
4103.097	*Si, Mn*	5	4
5645.830	*Si*	1	oblit.
5665.775	*Si*	1 N	0
5684.710	*Si*	3	1
5690.646	*Si*	3	1
5701.323	*Si*	1 N	00
5708.622	*Si*	3 N	0
5772.364	*Si*	3	0
5948.765	*Si*	6	2

SODIUM

The lines of sodium show a strong resemblance to calcium in their behavior in sun-spots. All of its lines are greatly strengthened and winged, and the D lines are in this respect perhaps the most striking feature of the entire spot spectrum.

The accompanying list gives the sodium lines found in Rowland's table. The scale of widening is from 1 to 3.

λ	Element	Intensity in Sun	Intensity in Spot	Character in Spot
4748.167	*Na?*	000	0	
4752.012	*Na?*	00	2	Widened 1
5682.869	*Na*	5	12	Widened 2
5688.436	*Na*	6	12	Widened 2; winged
5890.186	*Na*	30	90	Widened 3; immense wings
5896.155	*Na*	20	60	Widened 3; immense wings
6154.438	*Na*	2	8	Widened 3
6160.956	*Na*	3	9	Widened 3

The wings on D_1 and D_2 are of immense extent, on many of our plates overlapping each other between the two lines, and thus giving the effect of a marked weakening of the continuous spectrum. On one of the plates D_2 appears to be distinctly double, but in general the lines are single and greatly strengthened.

TITANIUM

The total number of titanium lines between the limits λ 4000 and λ 7000 which appear in Rowland's table, or may be identified with reasonable certainty from other sources with solar lines, is 432. Of these, 394 appear in our lists as affected, while the remaining 38, practically all of which are in the violet part of the spectrum, show no appreciable change of intensity. The percentage of lines affected

to the total number, accordingly, is 91. The entire number of lines strengthened is 320, of which 73 are blends and lines of double or doubtful origin, while the remaining 247 are due to titanium alone. A total of 74 lines are weakened: of these, 6 are blends and 22 of compound origin. The remainder, almost without exception, are lines which are enhanced in the spark spectrum. A single apparently contradictory case is that of λ 5284.281 assigned by Rowland to titanium. This is weakened from 2 in the sun to 0 in spots. It is, however, almost certain that this identification is wrong, since no line is found at this point either in the arc spectrum as given by Hasselberg or in Lockyer's list of enhanced lines.

It is hardly necessary to comment extensively on the general appearance of the titanium lines in the spot spectrum, since their behavior is so well known. In the yellow and red regions of the spectrum the changes of intensity are frequently very great: in some cases these changes are accompanied by much widening, while in others the entire effect is due to darkening of the lines, the widths remaining essentially unchanged. Among conspicuous examples of titanium lines which are very greatly affected we may mention the following which illustrate some of the different characteristics found in the case of this element:

λ	Intensity in Sun	Intensity in Spot	Character in Spot
5903.555	oo	7	Double: $\Delta = 0.09$
5922.334	o	6	Narrow and single
5938.035	ooo	6	Double: $\Delta = 0.08$
5953.386	1	6	Single
6064.853	oo	3	Wide double: $\Delta = 0.18$
6126.435	1	6	Probably double

The increase in the amount of strengthening toward longer wave-lengths is very marked in the case of titanium, the great number of lines changed in intensity making this effect comparatively easy of observation.

VANADIUM

There are a total of 176 lines due to vanadium between λ 4000 and λ 7000, either given by Rowland or easily to be identified with lines found in the arc tables of this element. Out of this number 165, or 94 per cent., appear on our lists as affected in sun-spots, a per-

centage almost identical with that for titanium. Fourteen of this number are weakened and the remainder, amounting to 151, are strengthened. A few of the weakened lines are blends, but all of the others are enhanced lines. The lines which are not affected nearly all occur in the violet part of the spectrum, a result similar to that found for the other elements the greater part of whose lines appear in sun-spots.

As is well known, some of the strengthened lines of vanadium in the less refrangible region of the spectrum show immense changes of intensity. Cases of increase from 0 or 1 in the sun to 6 or 8 in the spot are by no means uncommon, and in one instance a line at λ 6150.360 is strengthened from 0 in the sun to 11 in the spot. A great number of the vanadium lines in the red are double in spots and there are also a few cases of well-defined triplets. In view of the interest attaching to the vanadium spectrum in this region a list of a few of the more important lines is added.

λ	Intensity in Sun	Intensity in Spot	Character in Spot
6081.665	0	7	Close double
6111.872	0d?	8	Probably triple
6119.740	1	8	Widened 2
6135.580	00 N	7	Widened 3
6150.360	0 Nd?	11	Widened 3
6170.420	0000 N	8	Partial blend; probably double
6189.594	0000 N	4	Widened 3; double?
6199.398	0	7	Widened 3; triple?

GENERAL SUMMARY

At the close of this discussion of the behavior of the various elements in spots it will be of value to summarize the results already given in order to facilitate comparison of the different substances with one another. The total number of lines referred to in the table following is that given by Rowland with the addition in the case of scandium, titanium, and vanadium of some lines identified from tables of arc wave-lengths. The "enhanced" lines identified with solar lines are also added. In the percentage of lines affected, as given in the last three columns, the blends and compound lines are included, a procedure which of course introduces some error into the results, since the same line is occasionally counted for two

elements, and the element under which a given line is classified may not be that which is mainly instrumental in producing the change of intensity. For the comparison in view, however, this is not of serious consequence.

Element	Total Number Lines	No. Lines Strengthened		No. Lines Weakened		Percentage of Total Number		
		One Element	Compound Lines and Blends	One Element	Compound Lines and Blends	Strengthened	Weakened	Affected
Ca	60	43	16	...	...	98	...	98
Cr	386	200	75	36	31	71	17	88
Co	118	26	25	17	14	43	26	69
H	4	...	...	4	...	...	100	100
Fe	1108	300	127	258	98	39	32	71
Mg	8	3	...	1	...	38	12	50
Mn	167	68	31	15	9	59	14	73
Ni	251	48	24	106	26	29	53	82
Sc	45	30	...	3	...	67	7	74
Si	9	...	...	8	1	...	100	100
Na	8	8	...	...	...	100	...	100
Ti	432	247	73	46	28	74	17	91
V	176	114	37	9	5	86	8	94

"ENHANCED" LINES IN THE SPOT SPECTRUM

The behavior of enhanced lines in spots forms one of the most interesting features of their spectrum. Attention was called by Fowler[1] to the marked weakening of some of the more prominent enhanced lines, and summarized results for a considerable number of these lines of the more prominent elements were given by Hale, Gale, and myself in the paper already referred to.[2] In the following list are found all the enhanced lines between λ 3900 and λ 7000 for which the identifications seem reasonably certain. They are based largely on the tables of Lockyer in the more refrangible part of the spectrum, while in the yellow and red most of the lines have been identified from the Mount Wilson photographs of arc and spark spectra. Cases of compound lines, in which the enhanced lines do not form the principal parts, have been omitted, as having a tendency to give misleading results, and for the same reason some enhanced lines which on our plates cannot be separated from close neighboring lines have also been left out of the list.

[1] *Monthly Notices*, **66**, 361, 1906.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 11.

ENHANCED LINES IN THE SPOT SPECTRUM

λ	Substance	Intensity	Spot Mean	λ	Substance	Intensity	Spot Mean
3900.681	*Ti–Fe–Zr*	5	4	4316.962	*Ti?*	1	n. c.
3913.609	*Ti*	5d?	3	4321.119	*Ti?*	2	1
3916.545	*V*	3	2	4330.866	*Ti, Ni*	2	1
3932.161	*Ti*	1	1	4338.084	*Ti*	4	3
3952.103	*Mn–V*	2	1	4341.530	*Ti?*	2	1
3979.664	*Cr, Nd–Co*	4	2	4344.130	*Mn*	1N	n. c.
3987.755	*Ti?*	2	1	4344.451	*Ti–*	2	n. c.
3997.258	*Cr? V*	1	0	4351.000	*Ti*	1	n. c.
4002.808	*Fe*	0	0	4362.262	*Ni*	0	n. c.
4005.856	*V*	3	1	4367.839	*Ti*	2	1
4012.541	*Ti, Ce*	4	3	4367.882	—	00	
4012.631	*Cr*	0	00	4385.548	*Fe*	2	1
4015.760	*Ni*	3	1	4387.007	*Ti?*	1	0
4023.533	*V, Co*	3	2	4387.220	*Pb?*	1N	0
4025.286	*Ti–Ce*	3	2	4391.123	*Fe*	2	0
4028.497	*Ti–Ce*	4	2	4391.192	*Ti*	1	
4052.070	*Cr, Fe*	3	2	4395.201	*Ti*	3	2
4053.981	*Cr–Fe–Ti*	3	2	4396.008	*Ti*	1	0
4145.914	*Cr*	1N	0	4399.935	*Ti, Cr*	3	2
4161.682	*Ti*	4	3	4411.240	*Cr–Ti*	1	n. c.
4161.961	*Sr*	1	00	4417.884	*Ti–*	3	n. c.
4163.818	*Cr–Ti–*	4	2	4443.976	*Ti*	5	4
4172.066	*Ti, Fe*	2	1–2	4450.654	*Ti?*	2	1
4173.624	*Fe*	3	3	4464.617	*Ti?*	2	n. c.
4173.710	*Ti*	3		4468.663	*Ti–*	5	4
4174.240	*Ti*	0	00	4488.493	*Ti*	1	0
4179.025	*Fe*	3	1	4489.262	*Ti*	0	1
4183.619	*V*	2N	1	4489.351	*Fe*	2	
4184.472	*Ti*	2	1	4491.570	*Fe*	2	0
4202.514	*V*	0Nd?	00	4501.445	*Ti,–*	5	3
4205.186	—	1	1	4508.455	*Fe?, –*	4	2
4205.239	*V*	1		4515.508	*Fe*	3	1
4225.020	*Cr*	2N	n. c.	4520.397	*Fe?, –*	3	2
4225.378	*V*	0	n. c.	4522.802	*Fe*	3	1
4227.474	*Ti*	1N	0	4534.139	*Ti–Co*	6	5
4233.328	*Mn–Fe*	4	3	4549.642	*Fe*	2	0
4242.322	—	0	0	4549.808	*Ti–Co*	6d?	4
4242.535	*Cr*	2		4555.162	*Cr*	2	1
4242.615	—	2		4555.264	—	00	
4252.785	*Cr*	0N	00	4556.063	*Fe*	3	2
4253.157	*Mn*	1	n. c.	4558.827	*Cr?*	3	1
4262.086	—	1	0	4563.939	*Ti*	4	3
4262.142	*Cr*	1		4564.750	*V*	00	000
4279.225	*V? Mo?*	1N	n. c.	4572.156	*Ti–*	6	5
4284.382	*Cr*	2Nd?	1	4576.512	*Fe*	2	0
4290.377	*Ti*	2	n. c.	4583.892	—	00	2
4296.735	*Fe*	3	1	4584.018	*Fe–*	4	
4300.135	—	0	2	4588.381	*Cr*	3	1
4300.211	*Ti*	3		4590.126	*Ti*	3	2
4302.085	*Ti*	2	n. c.	4592.231	*Cr–*	1	0
4303.247	—	0	1	4600.383	*V*	00N	000
4303.337	*Fe*	2		4616.804	*Cr*	1N	0
4313.034	*Ti*	3	2	4618.971	*Fe–Cr*	4d?	3
4315.138	*Ti*	3	2	4634.254	*Cr*	2	0

ENHANCED LINES IN THE SPOT SPECTRUM—*Continued*

λ	Substance	Intensity	Spot Mean	λ	Substance	Intensity	Spot Mean
4635.489	*Fe*	0	oblit.	5226.707	*Ti*–	2	1–2
4657.380	*Ti?*	2	1	5237.493	*Cr?*	1	Wk. but lost in blend
4679.409	*Ni*	2N	1				
4708.846	*Ti*	2	1				
4764.108	*Ti–Ni*	4d	3	5316.790	*Fe*	4	2
4780.169	*Ti Co*	2	1	5336.974	*Ti*, –	4	3
4805.191	–	0	2	5381.221	*Ti*	2	1
4805.285	*Ti*	3		5418.979	*Ti?*	1	1
4824.325	*Fe Cr*	3	2	6042.315	*Fe*	3	2
4836.423	*Cr*	0	oblit.	6079.227	*Fe*	2	n. c.
4848.438	*Cr*	2	0	6103.400	*Fe*	4	2
4856.380	*Cr*	00	oblit.	6119.970	*Ni*	0	00
4864.505	*Cr*	1	0	6125.236	*Ni*	1	00
4874.196	*Ti*	0	000	6130.344	*Ni*	1	0
4876.586	*Cr*	1	00	6147.950	*Fe*	2	1
4876.666	–	00		6149.458	*Fe*	2	0
4911.374	*Ti*	1	0	6238.598	*Fe*	2	000
4924.107	*Fe*	1	2	6247.774	*Fe*	2	0
5018.629	*Fe*	4	2	6315.517	*Fe*	2	1
5072.479	*Ti*	0	000	6383.932	*Fe*	0N	oblit.
5097.175	*Fe Cr*	3	2	6417.133	*Fe*	1	0
5129.336	*Ti?*	3	1	6456.603	*Fe*	3	0
5154.244	*Ti–Co*	2	1	6491.800	*Ti*	1	0
5169.220	*Fe*	4	2	6516.311	*Fe*	2	0
5186.073	*Ti*	2	1	6627.797	*Fe?*	0	00
5188.863	*Ti*	2	n. c.	6663.487	*Fe*	1	0

The results given in this table are certainly remarkable as showing how universally the law of the weakening of enhanced lines in spots seems to hold. Out of a total of 144 lines 130 are distinctly weakened, none are strengthened, while 14 show no marked change. All of these 14 lines, moreover, lie to the violet of λ 4500, where the amount of change of intensity in the spot is decidedly less than toward longer wave-lengths. There is also a well-marked dependence of the amount of change in the spot on the amount of enhancement in the spark. Thus if we take, for example, the titanium lines between λ 4300 and λ 4600, a region which is most rich in enhanced lines, we find for 23 lines which give an average decrease of intensity in spots of 1.1 on Rowland's scale an amount of enhancement in the spark of 3.4, using Lockyer's values. On the other hand, 6 lines which show no change in spots give an enhancement of only 2.2 in the spark, and among these one which shows an enhancement of 4 in the spark may well be a compound line. Iron gives similar results

except that the amount of weakening in spots seems to be somewhat greater relatively to the amount of enhancement in the spark. Among especially marked cases we may refer to λ 4584.018 which is enhanced 7 in the spark and reduced 2 in spots; λ 4924.107 which is enhanced 8 in the spark and reduced 3 in spots; and the well-known chromospheric line λ 5018.629 which is enhanced 6 in the spark and reduced 2 in spots. The behavior of chromium is very similar to that of iron. Although the list given contains the greater number of the enhanced lines which can be identified with certainty in the solar spectrum, it seems very probable that a large number of the remaining unidentified lines in Rowland's table may also be of this character, since the arc spectrum was used in making the original comparisons.

Since the publication of the first paper by Mr. Hale, Mr. Gale, and myself, no important evidence has presented itself contradictory to the hypothesis that temperature conditions are sufficient to produce the changes of intensity observed among enhanced lines in spots. The marked weakening of such of the enhanced lines as are visible in the arc when we pass from the center of the arc to the outer part of its flame is certainly most readily accounted for on the same basis as the strengthening of lines in these sources, that is, reduction of temperature in the outer parts of the arc. In the case of a sun-spot a difference of temperature somewhat analogous to that of the flame of the arc, combined with the presence of an overlying solar spectrum sufficient largely to obliterate the characteristic features of the spot spectrum in the ultra-violet, would probably give reductions of intensity among the enhanced lines which in amount would closely resemble those actually found. On this basis we should expect lines in the yellow and red, showing an equal amount of enhancement with lines in the violet, to be considerably more weakened in spots than are the violet lines, and such is the case. The more strongly enhanced lines of iron in the red, for example, are nearly obliterated in the spot spectrum.

Another possible hypothesis to account for the weakening of the enhanced lines is due to Mr. Hale and was suggested in the earlier paper. It has been observed by Hartmann[1] and others that the

[1] *Astrophysical Journal*, **17**, 273, 1903.

presence of an atmosphere of hydrogen is conducive to bringing out enhanced lines in the electric arc. In spots the great weakening of the hydrogen lines indicates a marked diminution in the extent or density of the hydrogen envelope present above spots (possibly due to the formation of the hydride compounds, a point to which reference has already been made), and under such conditions we should expect a decrease in the intensity of the enhanced lines such as is found. Since it seems reasonably probable that the explanation of the observed increase in intensity of the enhanced lines in a hydrogen atmosphere is to be found in local rises of temperature in the radiating vapors produced at least momentarily by the presence of the hydrogen gas, this hypothesis is perhaps not contradictory to the view that temperature is the predominating factor in producing the diminutions of intensity which are observed.

Reference should also be made to Fowler's explanation of the cause of the weakening of the enhanced lines. As quoted in the earlier paper by Mr. Hale and myself, he writes in regard to this question as follows:

> It is probable that the vapors producing the enhanced lines are chiefly restricted to the higher chromospheric levels, and it is not yet clear whether the reduced intensity in spots is due to the withdrawal of these vapors from the spot, or to the absence of a sufficiently luminous background to strongly exhibit their absorption.

So far as is known, we have no direct evidence for concluding that the chromospheric vapors are withdrawn from spots. Moreover, it appears very doubtful whether the enhanced lines are chiefly restricted to the higher chromospheric level. Evershed[1] concluded from eclipse results that there is no evidence of differences in the relative intensities of enhanced lines in the higher or lower regions of the flash layer, and this is borne out by the results of some photographs of the chromosphere taken by myself with the tower telescope. On plates obtained so close to the sun's limb that almost the entire carbon fluting beginning at λ 5165 is shown as a mass of bright lines the enhanced lines maintain the same relative strength that they exhibit at a much higher level.

[1] J. Evershed, "Solar Eclipse of 1900, May 28.—General Discussion of Spectroscopic Results," *Philosophical Transactions*, A, **201**, 457.

BAND AND FLUTING SPECTRA IN SPOTS

The first observations of the titanium oxide flutings in the spot spectrum by Mr. Hale and myself were made on the two flutings beginning at λ 5598 and λ 7055. As soon as better sun-spot material became available it was possible to increase the number greatly, and with the aid of high dispersion plates of the titanium oxide spectrum to obtain identifications extending practically throughout the entire range of the spectrum under investigation. The plates used for the study of the titanium oxide spectrum were taken in the outer parts of the flame of a direct current electric arc, and like the sun-spot plates were obtained in the third order of the 30-foot spectrograph of the tower telescope. Accordingly, the solar and laboratory plates are directly comparable in scale, a fact which has proved of great convenience in identification of the lines for purposes of rapid comparison of the plates. I am indebted to Dr. Olmsted for most of the laboratory photographs. The list of titanium plates follows, with the regions measured upon each plate and the initials of the persons making the measures. As before, W. refers to Miss Wickham and B. to Miss Burwell. At present our comparisons extend only as far as λ 6760 for the titanium spectrum.

Plate	Region	Measured by
T 100.....	4500–4650	B.
T 91.....	4650–4885	W.
T 93.....	4870–5086	B. W.
T 94.....	5086–5300	W.
T 95.....	5300–5550	W.
T 96.....	5510–5720	W.
T 98.....	5720–5950	W.
T 98.....	5950–6150	W.
T 97.....	6146–6350	W.
T 99.....	6350–6760	W.

In comparing these results with our sun-spot lists and identifying the lines in the two spectra we have attempted to bear in mind several considerations. The first of these is, of course, the agreement in wave-length. In general we have limited discrepancies beyond which lines have not been identified in the two series of measures to 0.03 Ångström, and in the great majority of cases the differences are far below this amount. In a few instances where the character of

the lines indicates a blending, or offers a strong presumption for identity of the lines, this limit has been slightly exceeded, but only very rarely. In two regions of the spot spectrum, one near λ 5900 and the other at λ 6900, near the B group, use has been made of some atmospheric lines in the reduction of the sun-spot wave-lengths. In such cases corrections have been applied to the wave-lengths for the rotation of the sun, and for the earth's diurnal motion and the the effect of the eccentricity of the earth's orbit, when these amounted to more than 0.003 or 0.004 Angström. In addition to questions of wave-length, the relative intensities of the lines in the spectrum of the spot and of titanium have also been considered in determining the probability of the identity of lines.

A considerable number of lines in the spot spectrum which appear to coincide with fluting lines of titanium are present in Rowland's table, and in some cases are assigned identifications. This is, of course, to be expected from considerations of probability, when such great numbers of lines are under discussion. In most of these cases it is probable that the titanium lines are the principal cause of the rise of intensity in the spot. Similarly in the region of the *b* group of magnesium many titanium lines coincide with lines identified with magnesium hydride by Fowler. Such spot lines are probably also to be considered as of compound origin, especially such as fall to the red of λ 5167 where a strong titanium fluting begins.

The final results of our comparisons give the following number of identifications:

Region of Spectrum	Number of Identifications
λ 4500–λ 5000	660
λ 5000–λ 5500	800
λ 5500–λ 6000	1640
λ 6000–λ 6500	1400
λ 6500–λ 6760	380
Total	4880

It thus appears that nearly 4900 lines in the spot spectrum between λ 4000 and λ 6760 are to be ascribed with considerable probability to titanium oxide. With the extension of the titanium measures to λ 7000 this number would certainly be increased to above 5000, or fully 60 per cent. of all of the unknown lines in the spot spectrum.

The results given here are interesting as showing the increase in intensity of the flutings in the spot spectrum toward longer wave-lengths in the same way as in the titanium flame spectrum. To the violet of λ 4500 there is no certain evidence of the presence in spots of any fluting lines. Between λ 4500 and λ 5000 flutings become stronger in the arc, and the strong head at λ 4762 is well seen in the spot spectrum. Between λ 5000 and λ 5500 occur the two flutings with heads at λ 5167 and λ 5448. The first of these is confused in the spot spectrum with the magnesium hydride bands, but the second is a prominent feature in this region. At λ 5598 begins one of the strongest flutings in the whole spectrum, and it was from this fluting, as already stated, that the presence of titanium oxide in the spot spectrum was discovered. The great number of spot identifications between λ 5500 and λ 6000 is mainly due to the presence of this fluting. Beyond λ 6100 the titanium spectrum is very complex, the heads of flutings succeeding each other so closely that the whole region is a mass of lines. The number of lines found in the spot spectrum is correspondingly large. The fluting beginning at λ 7054 is not considered in this discussion but was treated in an earlier paper.[1] It is probably the most prominent fluting present in the spectra of spots.

The presence of magnesium hydride was discovered in the spot spectrum by Fowler, and the work of identification of spot lines is now being carried on by him. He has kindly furnished me with the wave-lengths of a considerable number of lines in the *b* region of the spectrum, and from these it appears that the total number of identifications will be large. A similar investigation is being carried on by Olmsted with calcium hydride. If we form approximate estimates of the number of identifications with these substances we obtain the following:

	Number of Identifications
Titanium Oxide . . .	5200
Calcium Hydride . . .	600
Magnesium Hydride . .	500
Total	6300

The total number of unknown lines in our sun-spot lists between λ 4000 and λ 7000, omitting the strong lines of Rowland's table,

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 15.

which evidently belong to arc or spark spectra, is about 8100. Accordingly, 78 per cent. of the whole number of unknown lines in the spot spectrum may be identified with lines in the spectra of these three compounds, and this percentage would be considerably increased if we considered only the stronger of the unknown lines. Under these conditions the statement made earlier in this paper that the presence of the spectra of these three compounds is sufficient to account for a decided majority of the unknown lines present in the spectrum of sun-spots seems to be justified.

As already stated, a comparison of the lines identified in the spectrum of spots with lines due to these compounds shows that it is almost certain that the titanium oxide flutings are not present in the solar spectrum. This is in agreement with the conclusion reached by Mr. Hale and myself from our earlier results. In the case of calcium hydride the evidence is similar and will be considered more in detail by Olmsted in his discussion of the spectrum of this compound. As regards magnesium hydride, there seems to be considerable evidence that the stronger lines are present as faint lines in Rowland's table. This is a matter which requires much more material for discussion, however. It will no doubt be investigated fully by Fowler. It is worthy of note that the earliest results on the spot spectrum in the *b* region by Mr. Hale and myself indicated that the more prominent spot bands were coincident with faint solar lines. Although the scale of the plates on which the measures were based was hardly sufficient to give a very high degree of accuracy, the evidence afforded by them is of considerable weight.

DOUBLE AND TRIPLE LINES IN THE SPOT SPECTRUM

A list of the more prominent doublets and triplets present in the spectrum of spots has been given by Hale in his paper dealing with the Zeeman effect.[1] For purposes of reference a complete list of all of the lines upon our plates which have either been measured as double or triple, or suspected of being such, is added. The list is divided into two parts, the first containing such lines as have actually been measured and so are unquestionably doublets or triplets, while

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 30; *Astrophysical Journal*, **28**, 315, 1908.

λ	Substance	Intensity in Sun	Character in Spot	Intensity of Components	Separation	Separation on T 219	Remarks
4232.887	*Fe*	2	Doublet	2:1	0.080		
4281.530	*Ti*	0	Doublet	0:0	0.074		
4373.415	*Cr*	1	Doublet	1:1	0.085		
4412.415	*Cr*	0	Doublet	1:0	0.059		
4416.636	*V*	0	Doublet	1:1	0.108		Red component wider
4421.733	*V*	0	Doublet	1:1	0.076		
4424.006	*Fe?* —	2	Doublet	1:0	0.069		
4428.711	*V–Cr*	1d?	Doublet	0:2	0.091		
4430.785	*Fe*	3	Doublet	2:2	0.096		
4436.313	*V*	0	Doublet	1:0	0.098		
4438.510	*Fe*	1	Doublet	0:0	0.105		
4444.385	—	0	Doublet	2:1	0.076		Probably due to *V–Ti*
4633.433	*Cr*	0	Doublet	00:000	0.098		
4768.276	*Co*	000	Doublet	000:00	0.096		
4852.743	—	2	Doublet	0	0.100		
5058.167	*Fe*	1	Doublet	00:000	0.124		
5225.695	*Fe*	2	Doublet	2:2	0.118		
5227.043	*Fe–Cr*	3	Doublet	2:2	0.090		
5304.355	*Cr*	0	Doublet	0:0	0.191		Possible triplet
5340.639	*Cr*	0	Doublet	00:00	0.102		
5387.165	*Fe, Cr*	0	Doublet	2	0.085		
5399.675	*Mn*	1Nd?	Doublet	1:1	0.119		
5461.762	—	0	Doublet	0:0	0.120		
5462.705	*Ni*	1	Doublet	0:0	0.141		
5712.996	*Cr*	0	Doublet	0:1	0.146		
5781.400	*Cr*	0	Doublet	3	0.125		
5781.967	*Cr*	0	Triplet	1:0:0	0.116:0.108		
5783.288	*Cr*	2	Doublet	2:2	0.136		
5784.080	*Cr*	3	Doublet	8	0.110		
5784.879	*Fe*	1	Doublet	0:0	0.122		
5785.188	*Cr*	2	Doublet	6	0.137		
5890.186	*Na*	30	Doublet	90	0.151		
5903.555	*Ti*	00	Doublet	4:3	0.118		
5916.475	*Fe*	3	Doublet	4:3	0.115		
5938.035	*Ti*	000	Doublet	3:3	0.102		
5941.985	*Ti*	00	Doublet	4:4	0.127		

λ	Substance	Intensity in Sun	Character in Spot	Intensity of Components	Separation	Separation on T 219	Remarks
6005.770	*Fe*	1	Doublet	2:1	0.120		
6007.540	*Ni*	1	Doublet	2	0.076		
6012.450	*Ni*	1	Triplet	0:0:00	0.116:0.117		
6024.281	*Fe*	7	Doublet	4:3	0.081		
6064.853	*Ti*	00	Doublet	1:2	0.160		
6081.665	*V*	0	Doublet	4:3	0.117		
6082.930	*Fe*	1	Doublet	1:1	0.141		
6111.872	*V*	od ?	Triplet	8	0.092:0.102		
6126.435	*Ti*	1	Doublet	3:3	0.085		
6127.684	—	0000N	Doublet	2:1	0.100		
6136.829	*Fe*	8	Triplet	9	0.064:0.070		
6137.210	*Fe*	3	Triplet	5	0.084:0.094		
6137.915	*Fe*	7	Doublet	8	0.100		
6151.834	*Fe*	4	Triplet	6	0.081:0.082		
6154.438	*Na*	2	Doublet	8	0.110		
6160.956	*Na*	3	Doublet	9	0.102		
6161.503	*Ca*	4	Doublet	8	0.120		
6173.553	*Fe*	5	Triplet	1:2:1	0.116:0.123	0.142:0.138	
6189.594	*V*	0000N	Doublet	2:2	0.117	0.185	
6199.398	*V*	0	Triplet	2:3:2		0.121:0.111	Probable triplet
6200.527	*Fe*	6	Doublet	8	0.098		
6213.644	*Fe*	6	Doublet	2:2	0.136	0.133	Fringe on violet component
6216.567	—	1	Triplet	2:3:2		0.134:0.141	
6219.494	*Fe*	6	Doublet	4:3	0.096	0.107	Shifted to violet
6224.198	*Ni?*	1	Doublet	0:1		0.115	
6224.715	*V*	000	Doublet	2:2		0.150	
6229.437	*Fe*	1	Doublet	2:1	0.112		
6232.856	*Fe*	3	Triplet	2:00:2		0.140:0.146	
6233.408	*V*	000	Doublet	3:2	0.109	0.272	Triplet on T 219 shifted to violet
6240.530	—	00	Doublet	2:1		0.140	
6243.055	*V*	000	Doublet	2:00		0.108	
6244.033	—	2	Triplet	00:1:0		0.123:0.120	
6245.832	—	1	Doublet	1:00	0.098	0.172	Shifted to red on one plate
6252.048	*V*	00	Triplet	2:3:2		0.104:0.110	
6254.050	—	00	Doublet	1:1		0.127	
6264.85			Doublet	3:2	0.105	0.128	No line in Rowland

λ	Substance	Intensity in Sun	Character in Spot	Intensity of Components	Separation	Separation on T 219	Remarks
6266.550	*V*	ooo	Doublet	2:2	0.175	0.245	Shifted to violet
6271.486	*Fe*	o	Doublet	1:1	0.101	0.144	Shifted to violet
6274.870	*V*	oo	Doublet	2:2	0.104	0.126	
6297.517	—	oooo	Triplet	ooo:ooo:ooo	0.091:0.093	0.100:0.093	
6301.718	*Fe*	7	Doublet	4:4	0.119	0.164	
6302.709	*Fe*	5	Triplet	1:1:0	0.121:0.116	0.177:0.177	
6303.985	*Ti*	ooN	Doublet	2:3	0.093	0.160	Shifted to violet
6312.456	*Ti*	oN	Doublet	2:2	0.091	0.170	Shifted to violet
6325.382	—	oooo	Doublet	2:2	0.080	0.124	Shifted to red on T 219
6330.316	*Cr*	1	Triplet	2:1:2	0.094:0.094	0.115:0.128	
6331.067	*Fe*	2	Doublet	2:ooo	0.149:0.180	0.180	Measured as triplet on one plate
6337.048	*Fe*	7	Doublet	3:2	0.151	0.180	
6344.371	*Fe*	4	Doublet	7	0.091		
6358.898	*Fe*	6	Triplet	3:4:3		0.123:0.125	
6363.090	*Cr, Fe*	2	Triplet	o:2:1	0.100:0.102	0.130:0.143	
6366.564	*Ti*	ooo	Doublet	2:2	0.099	0.169	
6384.886	*Ni*	1	Doublet	2:2	0.152	0.172	Shifted to violet on T 219
6400.217	*Fe*	8	Doublet	5:4	0.086		
6400.538	*Fe*	2	Doublet	2:3	0.088		Shifted to violet
6411.865	*Fe*	7	Doublet	10	0.086		
6462.784	*Ca*	5	Doublet	4:5	0.094		
6475.846	—	2	Triplet	3	0.086:0.087		
6494.004	*Ca*	6	Doublet	11	0.081		
6495.213	*Fe*	8	Doublet	9	0.085		
6496.688	*Fe*	2	Doublet	1:0	0.102		
6497.934			Doublet	1:1	0.148		No line in Rowland
6499.168	*Fe*	1	Doublet	2:2	0.116		
6499.880	*Ca*	4	Doublet	5:4	0.086		
6516.311	—	2	Doublet	oo:oo	0.087		
6531.667	*V*	ooo	Doublet	2:2	0.161		
6581.452	—	o	Doublet	1:1	0.143		
6633.995	*Fe*	2	Doublet	1:0	0.137		
6752.965	*Fe*	1	Doublet	0:0	0.214		
6840.086	—	1	Doublet	1:2	0.180		
6882.784	*Cr*	1	Doublet	0:0	0.226		
6925.543	—	1	Doublet	1:1	0.201		

the second part contains the more doubtful cases. Since the separation, even in the case of comparatively wide doublets, is rarely over 0.10 or 0.12 Ångström, it is clear that there must be a large number of lines which are widened but not separated with the dispersion employed. We hope with the use of more powerful spectrographs, in connection with the new tower telescope, to increase the number of measureable doublets considerably.

The separation of the lines which are given in the first list are, for the most part, means from measures made by Miss Burwell and myself. Since they are intended simply to indicate the character of the lines, and not to furnish the basis for a determination of the strength of the magnetic field in the spots under investigation, simple means have been taken for all of the plates employed except in a single instance. In this case, plate T 219, many of the separations show wide systematic variations from the mean values, thus indicating a marked difference in the strength of the magnetic field. Accordingly, for this plate the results are given separately. The same plate also shows some large differences in the intensity and character of the lines of certain elements, and will be made the subject of special study in a future investigation.

In the preceding table are given the lines which have been observed as double or triple on more than one plate, and the measured separations. The intensities of the separate components are found in the fifth column. Where these have been determined, the first value given refers in each case to the violet component. Where only one number is given it represents the total intensity considered as a single line.

In the table which follows are found the lines which are probably double or triple in the spot spectrum, but for which, in most cases, it has not been found possible to measure actual separations. The table includes the lines seen as compound upon any of our plates including plate T 219. There are, of course, a great number of lines at the limit of resolution, and the inclusion or exclusion of such cases is necessarily somewhat arbitrary. The list given, however, serves the purpose of indicating the relative number of such lines, and the elements whose lines most frequently appear in this form.

PROBABLE DOUBLETS

λ	Substance	Intensity in Sun	Character in Spot	λ	Substance	Intensity in Sun	Character in Spot
4573.041	—	oN	Doublet	5669.258	—	1	Doublet
4632.320	*Cr*	o	Doublet	5679.249	*Fe*	3	Doublet
4641.390	—	o	Doublet	5700.738	—	ooo	Doublet
4769.991	*Ti*	ooN	Doublet	5702.543	*Cr*	o	Doublet
4800.322	—	ooo	Doublet	5708.317	*Fe*	1	Doublet
4812.179	*Ni*	oo	Triplet	5712.357	*Fe*	2	Doublet
4849.357	—	o	Doublet	5738.453	—	o	Doublet
4872.332	*Fe*	4	Doublet	5742.068	*Fe*	2	Doublet
4896.625	*Fe*	1	Doublet	5747.890	—	1	Doublet
4913.311	—	oo	Doublet	5757.037	*Fe*	2	Doublet
4986.165	*Cr*	oo	Doublet	5761.052	*Ni*	2	Doublet
4993.531	—	o	Doublet	5798.728	A, —	ooo	Doublet
4993.864	*Fe*	o	Triplet	5837.925	*Fe*	o	Doublet
4995.835	—	oo	Doublet	5838.592	*Fe*	1	Doublet
5004.547	*Cr*	oood	Doublet	5847.221	*Ni*	1	Doublet
5068.485	*Cr, Ti*	oooo	Doublet	5853.902	*Ba?*	5	Doublet
5069.592	*Ti*	oood	Doublet	5866.675	*Ti*	3	Doublet
5192.523	*Fe*	5	Doublet	5881.500	—	o	Doublet
5228.268	*Cr*	ooo	Doublet	5884.655	—	ooo	Doublet
5243.526	*Cr*	oo	Doublet	5885.840	A(wv)	oo	Doublet
5245.901	—	oooo	Doublet	5896.155	*Na*	20	Doublet
5313.031	*Cr*	o	Doublet	5910.197	*Fe*	1	Doublet
5329.975	*Cr*	o	Doublet	5929.898	*Fe*	2	Doublet
5366.827	*Ti*	ooo	Doublet	5943.815	—	oo	Doublet
5375.516	—	ooo	Doublet	5949.566	*Fe*	1	Doublet*
5387.165	*Fe, Cr*	o	Doublet	5956.923	*Fe*	4	Doublet
5388.550	*V*	oo	Doublet	5969.795	—	ooo	Doublet
5391.660	*Fe*	2	Doublet	5981.043	—	oooo	Doublet
5405.554	—	1	Doublet	6003.239	*Fe*	6	Doublet
5413.889	*Mn*	ooN	Doublet	6007.540	*Ni*	1	Doublet
5429.349	*Ti*	oo	Doublet	6008.186	*Fe*	4	Triplet?
5436.508	*Fe*	1	Doublet	6008.785	*Fe*	6	Doublet
5436.802	*Fe*	1	Doublet	6013.715	*Mn*	6	Triplet
5447.130	*Fe*	6d?	Doublet	6016.861	*Mn*	6	Doublet
5449.369	*Ti*	ooo	Doublet	6020.401	*Fe*	4	Doublet
5476.778	*Fe*	3	Doublet	6022.016	*Mn*	6	Doublet
5487.959	*Fe*	3	Doublet	6032.885	—	ooooN	Doublet
5506.095	*Mn*	1	Triplet	6039.953	*V*	o	Doublet
5512.013	*Ti*	oo	Doublet	6065.709	*Fe*	7	Doublet
5530.997	*Ti*	ooN	Doublet	6079.227	*Fe*	2	Doublet
5537.928	*Mn*	oo)	Doublet	6085.470	*Ti, Fe*	2	Doublet
5538.025	*Mn*	oo)		6096.880	*Fe*	3	Triplet
5538.738	*Fe*	1	Doublet	6098.465	—	o	Triplet
5544.157	*Fe*	2	Doublet	6108.334	*Ni*	6	Doublet
5546.732	*Fe*	2	Doublet	6111.290	*Ni*	2	Triplet
5553.804	*Fe*	1	Doublet	6117.210	—	oo	Doublet
5597.290	—	ooo	Doublet	6120.460	—	oo	Doublet
5619.824	*V*	o	Doublet	6122.434	*Ca*	10	Triplet
5628.867	*Cr*	oo	Doublet	6129.190	*Ni*	1	Doublet
5641.206	—	1	Doublet	6143.390	—	oooN	Doublet
5654.091	*Fe*	1	Doublet	6148.040	*Fe*	3	Doublet
5658.097	*Y*, —	2	Doublet	6156.240	—	oo	Doublet
5659.817	—	o	Triplet	6157.945	*Fe*	5	Doublet
5667.739	*Fe*	2	Doublet	6162.390	*Ca*	15	Triplet

* Complicated by atmospheric line.

PROBABLE DOUBLETS—*Continued*

λ	Substance	Intensity in Sun	Character in Spot	λ	Substance	Intensity in Sun	Character in Spot
6163.630	*Ni*	2	Doublet	6420.169	*Fe*	4	Doublet
6163.968	*Ca*	3	Doublet	6439.293	*Ca*	8	Doublet
6169.249	*Ca*	6	Doublet	6450.033	*Ca*	6	Doublet
6169.778	*Ca*	7	Doublet	6452.536	*V*	ooN	Doublet
6170.730	*Fe–Ni*	6	Doublet	6455.820	*Ca*	2	Doublet
6176.669	—	oooo	Doublet	6464.897	—	oo	Doublet
6188.210	*Fe*	4	Doublet	6471.885	*Ca*	5	Doublet
6204.825	*Ni*	1	Triplet	6475.846	—	2	Triplet
6210.895	—	ooN	Doublet	6482.098	—	3	Doublet
6214.080	*V*	ooo	Triplet ?	6496.688	*Fe*	2	Doublet
6220.700	—	ooo	Triplet	6504.415	A(wv),*V*	o	Doublet
6240.530	—	oo	Doublet	6508.380	—	oooo	Doublet
6243.055	*V*	ooo	Triplet	6509.080	—	oo	Doublet
6243.320	—	1	Triplet	6518.599	*Fe?*	2	Doublet
6246.535	*Fe*	8	Doublet	6527.444	—	1	Doublet
6252.773	*Fe*	7	Doublet	6533.110	*Ni?*	o	Doublet
6254.382	—	1	Probably each component is double	6534.172	—,A(wv)	2	Doublet
6254.456	*Fe*	5		6569.460	*Fe*	5	Doublet
6256.572	*Ni–Fe*	6	Doublet	6597.807	*Cr*	1	Doublet
6257.090	*V*	oooN	Triplet	6604.837	—	1	Doublet
6265.348	*Fe*	5	Doublet	6608.280	—	o	Doublet
6269.080	*V*	ooN	Doublet	6625.276	—	o	Doublet
6280.833	*Fe*	3d	Triplet	6634.361	—	o	Doublet
6285.384	*V*	ooN	Triplet	6661.320	*Cr*	oo	Doublet
6293.030	*V*	ooo	Doublet	6663.487	—	1	Doublet
6296.582	—	oooo	Doublet	6705.352	—	1	Doublet
6298.007	*Fe*	5	Doublet	6719.880	*Ti*	ooN	Doublet
6311.722	*Fe*	1	Doublet	6880.887	—	oo	Doublet
6316.028	*Fe*	1	Doublet ?	6881.983	*Cr*	o	Doublet
6322.907	*Fe*	4	Triplet ?	6883.325	*Cr*	1	Triplet
6335.554	*Fe*	6	Triplet ?	6906.560	—	ooNd ?	Doublet
6336.329	*Ti*	ooN	Doublet	6914.823	*Ni*	4	Triplet ?
6355.246	*Fe*	4	Doublet	6977.198	—	oo	Doublet
6411.865	*Fe*	7	Doublet	6979.120	—	2	Doublet

The main results of this study can hardly be better summarized than by referring again to the principal characteristics of the spot spectrum, and the evidence bearing on each point afforded by the values given here.

1. A discussion of the various elements whose lines are strengthened or weakened in the spot spectrum indicates that the changes observed may be best accounted for on the basis of a reduced temperature in spots. A detailed study of the spectrum of iron furnishes especially strong evidence in this direction, and the weakening of the "enhanced" lines in the spot spectrum is also most simply explained on the same basis.

2. The presence of the spectra of titanium oxide, magnesium hydride, and calcium hydride is sufficient to account for the greater part of the unknown fluting and band lines appearing in the spot spectrum.

3. The discovery of the existence of a magnetic field in sun-spots by Mr. Hale provides a ready and sufficient explanation for the widening of large numbers of lines in the spot spectrum for which there is no marked change of intensity.

I wish to express my cordial appreciation to Mr. Hale for the opportunity to make use of a considerable amount of material secured by him in the course of his investigations on the spot spectrum, as well as for his interest and assistance during the progress of this research. I am also greatly indebted to the members of the Computing Division, and especially to Miss Burwell and Miss Wickham, for the careful and accurate manner in which they have carried out the great amount of difficult measurement involved in the reduction of the solar and the laboratory plates, and for their active interest throughout the entire course of the investigation.

MOUNT WILSON SOLAR OBSERVATORY
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THE ARC SPECTRUM OF VANADIUM IN THE REGION λ 5800 TO λ 7364

By H. SHAW

The present investigation of the arc spectrum of vanadium was undertaken at the suggestion of Professor Fowler, in order to provide greatly needed data for use in the examination of sun-spot spectra. The portion of the spectrum more refrangible than D has already been mapped with the necessary accuracy by Hasselberg,[1] Rowland and Harrison,[2] Exner and Haschek,[3] and Lockyer and Baxandall,[4] but the existing tables for the red end include only a small percentage of the lines.

The instruments employed were (1) a spectrograph of the Littrow pattern, having one 60° prism of $4\frac{1}{2}$ inch (114 mm) base, ($\mu_D = 1.6467$), and a collimating lens of 12 ft. (366 cm) focus, giving a linear dispersion ranging from 8.5 tenth-meters per mm at D to 16 tenth-meters per mm at λ 7200; (2) a Rowland grating of 10 ft. (305 cm) focal length, ruled surface 3.5 inches by 1.6 inches, with about 14,500 lines to the inch, which was mounted in the Littrow form by Mr. Eagle. Several photographs were taken with each instrument, using Wratten and Wainright's "Panchromatic" plates.

For the production of the vanadium spectrum the sulphate and chloride were volatilized in the ordinary way in the carbon arc, with a current of 8 to 12 amperes and a potential difference of 40 volts between the poles, the voltage at the main being 110.

For the determination of the wave-lengths, the spectrum of the iron arc was photographed adjacent to, and slightly overlapping, that of vanadium, and the measures were made on the overlapping part. The shutter exposing the two portions of the slit was entirely detached from the spectrograph in order to avoid relative shift of the two spectra.

[1] *Kongl. Svenska Vetenskaps-Akadem. Handl.*, **32**, No. 2, 1899.

[2] *Astrophysical Journal*, **7**, 273, 1898.

[3] *Sitzber. Kais. Akad. Wissensch. Wien*, **107** (2), 1908.

[4] *Proc. Roy. Soc.*, **68**, 189, 1901.

The plates were measured on a Hilger stage micrometer reading, by estimation, to 0.001 mm. The reduction to wave-lengths, in the case of the prism photographs, was made by the Cornu-Hartmann reduction formula, taking ranges of not more than 200 tenth-meters at a time. In the case of photographs taken with the grating mounted in the Littrow form, the distribution of the lines on the plate is not strictly normal, but the reduction to wave-length by the formula

$$\lambda = a + bs + cs^2$$

(s being the micrometer reading, a, b, and c three constants to be determined from three known lines) gives very satisfactory results if the range taken does not exceed 500 t.-m. For ranges greater than this an additional term ds^3 is found to be necessary.

By reference to numerous lines of iron, measured with those of vanadium, the equations were found to give wave-lengths not greatly exceeding the limits of error in setting the cross-threads. Fabry and Buisson's standard lines and Rowland's wave-lengths for the reference lines of iron were mainly used in the reductions, those in the region less refrangible than 6855 having been identified by E. J. Evans.[1]

Very consistent results were obtained by using the standards of Fabry and Buisson in the region more refrangible than λ 6500, beyond which their determinations do not yet extend, afterward converting the wave-lengths to Rowland's scale by curves constructed from differences between the standards and Rowland's corresponding measures. In the region less refrangible than λ 6500 the reference lines have been varied in the different reductions, the impurity lines of calcium and lithium present in the salts in some cases being taken as standards, and the mean of the wave-lengths thus obtained have been adopted. The results obtained in this way, however, were not quite so consistent as those on the violet side of λ 6500, the discrepancies being most pronounced between λ 6700 and λ 6900. It is very desirable that reliable arc standards such as those of Fabry and Buisson should be determined in the extreme red if very accurate wave-lengths are to be obtained in this region.

It is hoped that no greater error than 0.05 t.-m. occurs in the

[1] *Astrophysical Journal*, **29**, 157, 1909.

wave-length of any line, and it is probable that the errors are much less than this where the standards are reliable.

The only impurities of which there are any indications are sodium, lithium, and calcium, these being more pronounced in the chloride than in the sulphate. Sodium is represented by the D lines (reversed in most of the photographs) and by λλ 6154.44 and 6160.96; lithium by 6708.07; calcium by the lines attributed to that element in Rowland's tables, and by three additional lines which have been identified with the Fraunhofer lines for which Rowland gives the wave-lengths and intensities:

7148.435.....3 N
7202.485.....1 N
7326.462.....0

Photographs of the carbon arc alone showed only traces of these impurities.

TABLE OF WAVE-LENGTHS

In the following table the wave-lengths of vanadium lines less refrangible than λ 5800 are given; those in the first column (to λ 6500) being on the "international system" adopted by the Solar Union, those in the second column (also to λ 6500) being the corresponding values on Rowland's system. As the new standards are not available above λ 6500, the wave-lengths from λ 6500 to λ 7364 are given on Rowland's scale only. In the third column are given the estimated intensities of the lines on a scale of 10 for the strongest and 1 for the faintest capable of satisfactory measurement. The fourth column gives the wave-lengths from Rowland's "Preliminary Table of Solar Wave-Lengths" of lines in the sun not differing by more than 0.05 t.-m. from the values in the second column. There is no doubt that many of these coincidences are accidental. Those which are believed from considerations of intensity and character, to be due, or partly due, to vanadium in the sun are marked with a dagger (†). The fifth column gives the intensities of the solar lines according to Rowland's tables, and the sixth the origin, if any, ascribed to the line by Rowland.

TABLE OF VANADIUM LINES (λ 5800 TO λ 7364)

Wave-Length		Intensity (Max. = 10)	Nearest Line in Sun (Rowland)	Int. in Sun	Origin (Rowland)	Remarks
International System	Rowland System					
5799.96	0.17	2	5800.185	oo	A(o)	
5807.19	.40	3				
17.16	.37	2				
17.60	.81	3				
30.75	.96	4				
39.14	.35	1				
39.39	.60	1	39.600	ooo	A	
46.35	.56	4				
50.37	.58	2	50.553	oooo	A	
57.97	8.18	1	58.205	oooN		
79.40	.61	1				
5914.11	.32	1	5914.335	4	*Fe*	
24.59	.80	2	24.787†	oooo		
60.50	.70	1				
78.98	9.18	3	79.135†	oooN		
80.83	1.03	2	81.043†	oooo		
83.76	.96	1				
86.07	.27	1				
6002.39	.60	2				
02.62	.83	3	6002.870	oo	A(wv)	
08.76	.97	1				
16.17	.38	2				
17.95	8.16	1				
21.81	2.02	1	22.016	6	*Mn*	
25.45	.66	2				
39.74	.95	8	39.953†	o	*V*	
48.74	.95	1				
54.57	.78	1				
58.15	.36	5	58.385†	oooNd?		
63.35	.56	1	63.522	ooooN		
67.27	.48	2	6067.492	oooo		
81.45	.66	8	81.665†	o	*V*	
90.22	.43	9	90.429†	2	*Ti, V*	
6106.99	7.20	2				
11.64	.85	7	6111.872†	od?	*V*	
19.53	.74	7	19.740†	1	*V*	
28.35	.56	2				
35.35	.56	7	35.580†	ooN		
41.71	.92	1	41.938	7	*Fe, Ba*	Possibly due to *Ba*
50.14	.35	6	50.360†	oNd?	*V*	
70.33	.54	6				Rowland gives 70.420 as *V*
89.36	.57	3	89.594†	ooooN		
90.46	.67	1				
99.17	.38	8	99.398†	o	*V*	
6213.85	4.06	5	6214.080†	ooo	*V*	
16.34	.55	6	16.567†	1		Given by Young
18.34	.55	3				
21.33	.54	1	21.552	ooNd?	*Fe*, —	
24.50	.71	5	24.715†	ooo	*V*	
30.77	.98	7	30.943†	8	*Fe*	
33.18	.39	5	33.408†	ooo		Given by Fowler

TABLE OF VANADIUM LINES—*Continued*

Wave-Length		Intensity (Max. = 10)	Nearest Line in Sun (Rowland)	Int. in Sun	Origin (Rowland)	Remarks
International System	Rowland System					
6236.31	.52	1				
40.14	.35	4	6240.370†	00		
42.81	3.02	4	43.055†	000	*V*	
43.08	.29	10	43.320†	1		Given by Mitchell
45.22	.43	2	45.413	0000		
47.53	.74	1	47.774	2		
51.81	2.02	9	52.048†	00	*V*	
56.91	7.12	4	57.090†	0000N		
58.58	.79	4	58.780†	00		Rowland gives 58.570 as *V*
61.21	.42	4				Rowland gives 61.501 as *V*
66.33	.54	4	66.550†	000		
68.84	9.05	5	69.080†	000N	*V*	
71.68	.89	1				
74.64	.85	8	74.870†	00		
82.36	.57	2				
85.17	.38	8	85.384†	00N	*V*	
86.92	7.13	1				
92.82	3.03	8	93.030†	000	*V*	
95.25	.46	2				
96.49	.70	8	96.715†	0000		Rowland gives 96.582 as *V*
6304.39	.60	2	6304.545	000N		
09.77	.98	1				
11.53	.74	3	11.722†	1	*Fe*	
18.39	.60	1				
21.26	.47	2	21.505	0000	A(wv)	
24.72	.93	2	24.894	0000		
26.84	7.05	4	27.038†	0000		
27.30	.51	1	27.485	0000		
39.11	.32	3	39.335†	2	*Ni*	
49.47	.68	3				
55.62	.83	1				
57.32	.53	3				
58.84	9.05	2				
61.30	.51	2				
74.53	.74	1				
79.37	.58	2				
81.31	.52	1				
84.52	.73	1				
93.35	.56	2				
98.17	.38	1				
6407.13	.34	1	6407.350	0000N		
17.09	.30	1				
25.08	.29	1				
30.54	.75	3				
31.69	.90	3	6431.890	0000		
33.23	.44	2				
35.22	.43	2				
38.14	.35	1				
45.23	.44	1				
47.88	8.09	1				
50.97	1.18	1				

TABLE OF VANADIUM LINES—*Continued*

Wave-Length		Intensity (Max. = 10)	Nearest Line in Sun (Rowland)	Int. in Sun	Origin (Rowland)	Remarks
International System	Rowland System					
6452.35	.56	5	52.536†	ooN		
67.03	.24	1	67.212	oooo		
88.12	.33	2				
90.77	.98	1	91.015	1	A(wv)	
96.94	7.15	2	97.128	4	*Fe*	Possibly due to *Ba*
98.86	9.07	1				

TABLE OF VANADIUM LINES—*Continued*

Wave-Length Rowland's System	Intensity (Max. = 10)	Nearest Line in Sun (Rowland)	Int. in Sun	Origin (Rowland)	Remarks
6504.40	5	6504.415†	o		
09.04	2	09.080	oo		
27.64	2				
31.66	8	31.667†	ooo		Given by Mitchell as 6532.0
35.47	1				
43.76	4				
50.33	1				
58.28	3				
66.13	3				
69.07	2	69.040	oooN	A(wv)	
79.20	2				
95.59	1	95.590	oooo		
6606.20	7	6606.160†	oooN		
08.08	3				
19.40	1				
23.83	2				
25.05	6	25.077†	ooooN		
33.53	2				
44.03	2				
58.89	1				
62.64	1				
93.88	2				
6732.22	1				
53.20	7	6753.265†	oooN		
60.35	2				
66.68	7				
77.54	1				
80.59	1				
85.20	7				
86.55	3				
6803.39	1				
08.32	1				
12.61	7	6812.605†	oooN		
19.43	1				
30.16	3				
32.67	4				

TABLE OF VANADIUM LINES—*Continued*

Wave-Length Rowland's System	Intensity (Max. = 10)	Nearest Line in Sun (Rowland)	Int. in Sun	Origin (Rowland)	Remarks
6839.82	3				
42.11	5				
60.66	1				
62.16	1	62.210	o		
71.10	5				
71.75	4				
76.43	2				
84.20	2				
90.41	1	90.460	ooo		
94.30	2	94.320	oooN		
95.95	1				
6906.56	1	6906.560	oooNd?		
16.36	2	16.325	oooN		
23.45	1				
26.22	1	26.170	oooo		
41.22	3	41.260	oooN	A(wv)	
66.20	1	6966.158	ooo		
74.83	5				
81.81	4	81.860	ooo	A?	
89.89	1				
7026.32	5				
32.46	1				
38.26	1				
45.28	1	7045.313	ooo		
49.36	1				
52.62	1	52.665	oooN	A?	
59.62	1				
82.93	1				
90.92	2				
92.35	1				
93.13	1	93.120	oooo		
7135.97	1				
39.97	1	7139.973	oooN		
51.66	2				
55.67	1				
82.33	1				
7216.60	1				
21.44	1	7221.492	o		
64.68	2	64.676	oo	A	
7339.54	2				
57.16	2				
62.14	1				
63.24	1				
63.80	1				

OXIDE FLUTINGS

In addition to the lines produced under all conditions when a vanadium salt is volatilized in the arc, there are also occasionally produced flutings fading toward the red. These have well-defined heads,

in some cases double. They appear when the carbon pole is well charged with fused salt and is burning in air or oxygen. On their appearance a sudden drop in the potential difference between the poles occurs and the arc will then continue to run even when the poles are separated by two centimeters or more, the voltage at the main being 110. The flutings do not occur either in vacuo or in hydrogen, nor apparently at any time except in presence of oxygen. Hence we are justified, tentatively at least, in considering them as due to vanadium oxide.

The following are the positions on the international system of fluting heads:

5011.1	weak, nebulous	6086.70	strong
5057.2	weak, nebulous	6087.54	
5230.3	moderate	6477.44	strong
5276.2	moderate	6478.55	
5469.44	strong	7155.5	weak
5470.13		7160.1	
5737.54	strong		

I am indebted to Professor Fowler for valuable help in the investigation.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY
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ON NEW MEMBERS OF THE SYSTEM OF THE STARS β, γ, δ, ϵ, ζ, *URSAE MAJORIS*

By EJNAR HERTZSPRUNG[1]

It is known that five stars of the constellation *Ursa Major*, β, γ, δ, ϵ, ζ, have approximately equal proper motions, and therefore probably are moving in parallel lines in space, with equal velocities. From this point of view, H. Ludendorff has subjected the five stars to a thorough investigation, published in the *Astronomische Nachrichten*, **180**, 265, 1909. He made, in particular, new determinations of the radial velocities of the spectroscopic binaries β and ζ *Ursae Majoris*, thereby making possible a more accurate knowledge of the system. I am informed, in a private letter of the author, that a search was not made for further stars belonging to the group, because Höffler states[2] that he had tested all the stars of the Auwers-Bradley catalogue in a large region, with entirely negative results.

Several stars have, however, incidentally come to my attention which may be suspected of belonging to the system: the first of these are *37 Ursae Majoris* and *a Coronae Borealis*, of which it may be stated as very probable that they belong to the system. Since the angular distance between these two stars is 59°.7, the absolute distance must be of the same order of magnitude as their distance from our sun. It was, therefore, desirable to extend the search to stars still farther removed from these, and to such as had a different value of the proper motion (different parallax). In this search, I first employed Kapteyn's discussion of 2618 Bradley stars (*Publications of the Astronomical Laboratory of Groningen*, No. 9), comparing upon a celestial globe the direction of the proper motion each star would have if it belonged to the system with that observed. In order to base my conclusions on the most accurate proper motions, I first sought out among the stars which were then in the best agreement those which occur in the New Fundamental Catalogue of the Berlin

[1] Translated from the *Nachrichten der K. Gesellschaft der Wissenschaften zu Göttingen*. Mathematisch-physikalische Klasse. 1909.

[2] *Astronomische Nachrichten*, **144**, 369, 1897.

Astronomisches Jahrbuch. The eleven stars thus selected make up the first part of Table I. It is to be noted that *Sirius* is found among these stars. The accuracy with which the direction of its large proper motion is known, yields a good geometrical position for the point of radiation. I first reckoned the radiant point as the intersection of the proper motions of *Sirius* and of a fictitious star located at the center of gravity of the five stars named in the title of this paper ($\alpha = 183°.22$, $\delta = +56°.14$, for 1900), the proper motion of which was directed toward Ludendorff's apex ($\alpha = 303°.2$, $\delta = -36°.6$, for 1900). The point was determined, in the second place, on that great circle defined by the proper motion of *Sirius*, which yielded the smallest sum of the squares of the geometrical deviations of the remaining proper motions (Table I, col. 8). In this computation the most doubtful star, β *Eridani*, was omitted. These two determinations, dependent upon the proper motion of *Sirius*, yield values agreeing within $\frac{1}{10}$ of a degree, namely,

$$\alpha = 127°.8, \quad \delta = +40°.2, \text{ for } 1900.$$

These co-ordinates are made the basis of the computed values in the table. Ludendorff found $\alpha = 123°.2 \pm 3°.0$, $\delta = +36°.6 \pm 3°.5$ (mean error).

The difference between the observed and computed direction of the proper motion is given in col. 7 of Table I, and in col. 8 the sine of this difference is multiplied by the annual proper motion. These last values, therefore, yield the smallest geometrical variation of the annual proper motions which are competent to bring about an agreement between observation and computation.

In connection with the angular distances of the stars from the assumed radiant point (Table I, col. 9), the radial velocities found for the four stars: α *Canis Majoris*, β and ζ *Ursae Majoris*, and α *Coronae*, yield, by least squares, a velocity of 18.4 km per sec. relative to the sun for the system. The radial velocity computed from this for each star is found in col. 10. Finally, the absolute parallaxes in col. 12 were computed with the assistance of the amounts of the annual proper motions. The absolute point of convergence of the system lies near $\alpha = 285°$, $\delta = -2°$, or, in galactic co-ordinates, $l = 0°$, $b = -5°$, and the absolute velocity amounts to 28.8 km per sec.

TABLE I

	R. A. 1900	Decl. 1900	Annual Proper Motion μ	Direction of Proper Motion		O.−C.	μ sin (O.−C.)	Distance from Star to Convergence Point RS	Radial Velocity		Computed Parallax π	Angle Pole Radiant-Star R	Rectangular Co-ordinates (Unit = Cosec 1″ Astron. Units)		
				O.	C.				C. km	O. km.			x	y	z
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	°	°	″	°	°	°	″	°			″	°			
β Eridani	75.73	− 5.22	0.1188	228.1	221.3	+6.8	+.0141	65.9	− 7.5		0.034	239.4	−13.8	−23.3	12.1
β Aurigae	88.05	+44.94	.0455	260.1	265.2	−5.1	−.0040	29.4	−16.0	(−21)	.030	292.6	6.2	−15.0	28.8
α Canis maj.	100.19	−16.58	1.3235	203.6	203.6	.0	.0000	62.3	− 8.5	− 7.4	.387	210.1	− 2.0	− 1.1	1.2
37 Ursae maj.	157.18	+57.60	.0756	61.8	60.0	+1.7	+.0023	25.6	−16.6		.045	37.4	7.6	5.8	19.9
β Ursae maj.	163.95	+56.92	.0871	72.3	70.0	+2.3	+.0035	28.7	−16.1	−16.8	.047	42.2	7.6	6.9	18.7
δ Leonis	167.20	+21.07	.2017	132.5	128.8	+3.6	+.0032	38.5	−14.4		.084	107.9	− 2.3	7.1	9.3
γ Ursae maj.	177.14	+54.25	.0945	88.5	87.5	+1.1	+.0018	35.5	−15.0		.042	49.8	8.9	10.5	19.3
δ Ursae maj.	182.62	+57.59	.1095	88.6	87.6	+1.0	+.0018	38.7	−14.4		.045	44.5	9.8	9.7	17.2
ε Ursae maj.	192.41	+56.50	.1140	95.6	96.9	−1.3	−.0026	44.0	−13.2	(−13)	.042	45.8	11.4	11.7	16.9
ζ Ursae maj.	199.98	+55.45	.1250	101.8	103.4	−1.7	−.0036	48.4	−12.2	−12.6	.043	46.2	11.9	12.5	15.3
α Coronae	232.61	+27.05	.1580	128.5	132.0	−3.4	−.0094	83.1	− 2.2	+ .4	.041	60.1	12.0	20.9	2.9
Groombr. 1930	191.08	+60.87	.075	88.5	91.4	−2.9	−.0037	43.0	−13.4		.028	39.1	18.6	15.1	25.7
78 Ursae maj.	194.11	+56.91	.115	99.5	98.0	+1.5	+.0031	44.9	−13.0		.042	44.6	12.0	11.8	16.8

As to the probability that the separate stars belong to the system, let us first consider *Sirius*. Since we know for this star the amount and direction of its proper motion, as well as its radial velocity and parallax, the three components of its velocity relative to the sun may be computed. All three agree, within the precision of the observations, with the velocity found for the five stars in *Ursa*. Let it be remarked that the assumed radiant point ($\alpha = 127°.8$, $\delta = +40°.2$) lies 97° distant from the apex of the solar motion ($\alpha = 266°$, $\delta = +33°$), so that the members of the group here under consideration may be separated with comparative ease from the principal streams of the other stars. Only about one among a thousand arbitrarily selected stars would yield as good agreement as *Sirius* does. On the assumption, which is accordingly very plausible, that *Sirius* and the five stars of *Ursa Major* have equal absolute velocities, we may say that the radial velocities of these stars may be checked by measurement of the parallax of *Sirius*.

In the case of several of the other stars, we unfortunately still lack a knowledge of the radial velocities. Ludendorff has in prospect a remeasurement of this quantity for the center of gravity of β *Aurigae*. For the radial velocity of the center of gravity of ϵ *Ursae Majoris*, Ludendorff gives, with reserve, the provisional value of -13 km per sec.

The parallax of δ *Leonis* may be expected to be measurable.

Ludendorff has already called attention to a peculiar progression in the deviation between observed and computed directions of the proper motions of the five stars in *Ursa Major*. This progression (Table I, cols. 7 and 8) becomes more evident in the extension of the system which I have here undertaken, but it nevertheless always remains within the permissible errors of observations. I have found no plausible physical explanation of this progression; perhaps, indeed, stellar systems of the sort here discussed might serve in the determination of systematic errors of observation.

I have looked up a number of other stars, whose proper motion is directed approximately toward the above point of convergence. Determinations of the radial velocities and of the parallax are needed, however, before anything further can be said about them. Nevertheless the membership in the system of *78 Ursae Majoris* may be

stated to be very probable, and that of *Groombridge 1930* as probable. These two stars are added to the eleven principal stars in Table I. *78 Ursae Majoris* is a visual double star (Burnham, *General Catalogue*, No. 6348). The position angle has increased about 20° in fourteen years, with a distance of 1″.4. This orbital motion is in good accord with the computed parallax of 0″.042. *78 Ursae Majoris*, by the way, was already mentioned by Höffler. *κ Bootis* (Σ 1821), is, further, somewhat suspicious, but the different determinations of its proper motion differ by a pretty large amount.

TABLE II

1	Stellar Magnitude H. R. m 2	Magnitude Reduced to $\pi=1''$ $m+5\log\pi$ 3	Spectrum	
			Maury 4	H. R. 5
β Aurigae	2.07	−5.53	VIII a	Ap
ε Ursae maj.	1.68	−5.18	VIII P	Ap
α Coronae	2.31	−4.62	VIII ab	A
β Eridani	2.92	−4.44	IX b	A 2
ζ Ursae maj. A	2.40	−4.42	VIII a	Ap
γ Ursae maj.	2.54	−4.34	VIII b	A
β Ursae maj.	2.44	−4.20	VIII a	A
α Canis maj.	−1.58	−3.64	VII a	A
δ Ursae maj.	3.44	−3.28	IX b	A 2
ζ Ursae maj. B	3.96	−2.86		A 2
δ Leonis	2.58	−2.80	IX b	A 2
g Ursae maj.	4.02	−2.80	IX b	A 5
78 Ursae maj.	4.89	−1.99		F
Groombr. 1930	5.87	−1.86		F
37 Ursae maj.	5.16	−1.56		F

It is striking that so many of the stars here in question are double: this is certainly true of nine of the fifteen stars in Table II.

The direction of the proper motion of *α Geminorum* might arouse the suspicion that it also belonged to the system. Its spectrum, VIII *a*, according to Miss Maury, is very similar to that of the other bright members, and *Castor* has, in common with *Mizar*, the spectroscopic duplicity of the two components. Nevertheless, the radial velocities of the centers of gravity of the systems of α_1 and α_2 *Geminorum*, respectively −1.0 and +6.2 km per sec., sufficiently show that these stars do not belong to the system. The computed parallax also turns out too large.

The absolute brightness, reduced to a parallax of 1″, was com-

puted with the aid of the computed parallaxes and the stellar magnitudes of the *Revised Harvard Photometry* (*Harvard Annals*, **50**), and the stars are arranged accordingly in col. 3 of Table II. The combined light was taken for the spectroscopic binaries. A comparison of the spectra, given in cols. 4 and 5, suggests an increasing development of the spectrum, with a decline in the absolute brightness. In this respect, the system here treated behaves in a manner analogous to the physically connected *Pleiades;* while for the *Hyades* it is known that this is true only for a part of the stars, and that marked deviations occur—all of which hitherto pointed in the direction that these stars are more red than would be expected from their absolute brightness, a phenomenon that is also known to us in case of other stars like *α Boötis*, *α Tauri*, *α Orionis*, *α Scorpii*. For 16 *Hyades* (with spectra between A and F, average A 4 F) the brightness, reduced to a parallax of 1″, averages −2.86 magnitudes; this, together with the data given in Table II, indicates that the *Hyades*, and the stars of the system under discussion, have on the average equal absolute brightness for spectra between A and F.

The question is of particular interest how many stars of low absolute brightness may belong to the group. Among the 307 stars having an annual proper motion of more than 0″.5, which Kobold treated in his book *Bau des Fixsternsystems*, there occurs no strikingly large number for which the proper motion is directed with sufficient accuracy toward the above point of convergence. For some of these stars, determinations of parallax are available, but in all cases, with the exception of *Sirius*, a much smaller value was found than corresponded with the system. The parallax, as may readily be seen, cannot fall below $\frac{1}{4}$ of the magnitude of the annual proper motion, and this is, for very few stars with large proper motion, the case. It therefore remains highly probable that the distances between one member of the system and its neighbors are to be designated as decidedly "stellar." In case this also applies to other systems, it becomes clear why Kobold found among the above 307 stars only uncertain traces of the systems; even if it is assumed that the majority of the stars group themselves in such systems. To find this out, it would be necessary to go down to decidedly smaller proper motions, but for this the accuracy hitherto has been rarely adequate.

TABLE III

O = *observed*; C = *calculated*

1	R. A. 1900 2	Decl. 1900 3	Annual Proper Motion 4	Direction of Proper Motion O. 5	Direction of Proper Motion C. 6	Distance from Star to Point of Convergence 7	Radial Velocity C. km. 8	Magnitude 9	$m+5 \log \pi$ 10	Spectrum 11	Parallax C. π 12	Parallax O. 13
	°	°	″	°	°	°					″	″
41 H. Androm.	23.92	+42.11	0.82	99.4	99.4	69.3	+15.6	5.10	−0.01	F	0.095	0.116 S.
δ Trianguli	32.74	+33.77	1.18	101.6	101.7	60.9	+21.4	5.07	0.89	G	.146	.108 F., .123 S.
θ Ursae maj.	141.54	+52.13	1.10	240.2	239.9	60.3	+21.8	3.26	−1.06	F 8	.137	.098 F., .054 K., .098 P.
11 Leonis min.	142.42	+36.26	0.76	250.0	250.0	54.1	+25.8	5.48	0.61	K	.106	−.016 C., .075 J.
AOe 10603	151.31	+49.96	1.44	249.8	249.9	65.0	+18.6	6.76	2.94	K	.172	.333 B., .185 K., .178 P., .138 F.
Lal 27742	227.06	+19.65	0.68	296.3	296.5	128.1	−27.1	6.41	1.26	G	.093	.054 S. E.
P. XXIII, 267	359.91	+34.10	0.76	82.8	82.8	92.0	− 1.5	6.23	0.81	F	.082	.004 C.

The computed rectangular co-ordinates in space of the separate stars are given in cols. 14, 15, and 16 of Table I. The distance of a star with a parallax of 1″ was taken as the unit. The sun lies at the origin, and the Z-axis is directed toward the radiant point; the X–Z plane contains the earth's axis. If we designate the triangle Pole-Radiant-Star with *PRS*, we have, π being the parallax,

$$x=\frac{\sin RS \cos R}{\pi}, \quad y=\frac{\sin RS \sin R}{\pi}, \quad z=\frac{\cos RS}{\pi}.$$

The quantities *RS*, *R*, and π are found in cols. 9, 12, and 13 of Table I.

ADDENDUM REGARDING THE *HYADES*

According to Lewis Boss,[1] the *Hyades* have a convergent point at $\alpha=92^\circ.15$, $\delta=6^\circ.93$, for 1900. I assumed in the first values the values $\alpha=92^\circ.3$, $\delta=+7^\circ.1$, for 1900, and a velocity relative to the sun of 44.0 km per sec. Among the above-mentioned 307 stars investigated by Kobold, I have sought out those which gave the best agreement between observed and computed direction of proper motion, and I have enumerated seven of them in Table III. As will be seen from a comparison of cols. 5 and 6, the proper motions of these seven stars are so accurately directed toward the convergent point of the *Hyades*, that they can scarcely all of them be strangers to this group. Determinations of the radial velocity are available only for θ *Ursae Majoris*. Küstner found +15 km, which value differs by 7 km from the computed value of +22 km. The star has a physical companion of magnitude $13\frac{1}{2}$ at a distance of 5″ (Burnham, *General Catalogue*, No. 5123), so that the radial velocity is possibly influenced a little by the orbital motion.

In the observed parallax given in col. 13, the following abbreviations are used:

B=Ball; C=Chase; E=Elkin; F=Flint; J=Jost; K=Kapteyn; P=Peter; S=Smith.

The parallax of the comparison stars, 0″.008, was added to the original figures.

For the double star *55 Tauri*, which physically belongs to the *Hyades*, a parallax of 0″.025 is computed from the orbital motion,

[1] *Astronomical Journal*, **26**, 31, 1908.

on the assumption that the sum of the two masses is equal to that of the sun. This value agrees exactly with that computed by Lewis Boss, so that we here again arrive at masses similar to that of the sun. The two double stars, *80 Tauri* and *Hu* 1080 (Burnham, *General Catalogue*, No. 12,992), similarly belong to the group, and give promise, within a reasonable time, of offering the possibility of an orbital motion.

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UPON THE SEPARATION OF THE SPECTRAL LINES OF THORIUM IN THE MAGNETIC FIELD, I

By B. E. MOORE

The spectral photographs of this substance were taken during the winter semester of 1906 at the Physical Institute of the University of Göttingen at the suggestion of the director, Professor W. Voigt, who courteously placed all the necessary equipment at my disposal and enthusiastically promoted the investigation. This was at the time I studied the spectra of barium, yttrium, zirconium, and osmium (*Astrophysical Journal*, **28**, 8, 1908). The thorium lines were found to be too numerous and entangled to admit of ready identification and were therefore laid away for study at a more opportune time. One component or more of a line is frequently found between the components of another line. Two components of different lines may lie so close together that one can tell with difficulty to which of the two lines they may belong; or two or more components may overlap. These overlaps are of various degrees, i. e., in one extreme they may be merely touching each other and form one broad line; or in the other extreme be accurate duplicates in position and produce an intensified sharp line. How complicated this becomes, may be illustrated by one small region six Ångström units wide, about the separation of D_1 and D_2, where there were found components of thirteen lines. These entanglements are usually unraveled by studying the photographs of two field-intensities. Such a method I have pursued but unfortunately the field-strengths differed by only 20 per cent., where 40 per cent. difference was desirable. Sometimes the overlaps are so sharp that one falls into no particular error in assuming them to be the centers of two overlapping components. But one cannot regard this procedure as accurate as measurements of isolated components. Neither have I regarded the measurements upon the weaker field plates alone as accurate as the other measurements. Further they would be less accurate than lines measured for both field-strengths and in both first and second order. All the less accurate measurements have been inclosed in parentheses.

A characteristic of the thorium spectrum is that the components which vibrate perpendicular to the lines of force, the *s*- components, are usually narrower and sharper than those which vibrate parallel thereto, the *p*- components. This was helpful in isolating the *s*- components. The thorium lines with no magnetic field were usually very sharp, but there were exceptions, and these were lines which behaved peculiarly (see below). This sharpness of the no-field lines led to the following method of identifying the lines and components thereof for both kinds of vibrations—a method which saved a great amount of labor and led to some important discoveries. Each set of plates was cut in two longitudinally through the center; and the edges of the lines of either the *p*- or *s*- components brought into juxtaposition with the ends of the lines upon the no-field plates in the center of the field of view of the microscope. One-half of the field of view of the microscope had a fixed cross-wire (a diamond mark on glass); and upon the other half of the field of view there was a movable system of lines in pairs of various separations. A sharp no-field line was brought under the single fixed line and the corresponding *s*- or *p*- line placed as nearly symmetrical as possible therewith, by hand adjustment, under the other cross-wire system, and the final adjustment made by a micrometer which controlled this cross-wire system. With the aid of another micrometer the whole microscope could be moved, and by means of this motion one could pass readily from one line to another coincidently upon both sets of plates. In this way a series of readings was then taken for a number of lines in the field of view upon both sets of plates. The majority of these adjacent lines were duplicates in position within the errors of setting the microscope. The error in setting the microscope for the *p*- components was twice as great as the corresponding error for the no-field lines. The latter also can be adjusted more accurately than the double readings of the *s*- components of a triplet. By this method of comparison I discovered that a great many of the lines were unsymmetrical in position, assuming that the lines which could be brought into juxtaposition were symmetrical. If, however, as Professor Voigt writes me, there should be, for instance, a one-sided displacement of the *p*- or *s*- components, it might be impossible to detect it, as the plates would be displaced as a whole. Such a

displacement or dissymmetry is theoretically derived by Professor Voigt.[1] It involves the period of the vibrating ion and a constant which depends upon the absorption and emission of the ion. This constant would vary from ion to ion, and, therefore, there would be large variations from line to line, unless the lines arose from the same ion. From Geiger's[2] investigation, the displacement is only one two-thousandth part of the total separation of the D_1 line for a field-strength of 2400 lines to the square centimeter. But for the red *K* line corresponding to D_2 Geiger's data give a ratio of 3 per cent. The latter would be observable unless the lines were diffuse. We may, then, in a great many cases expect the effect to be too small to be observable. Even if it were generally observable in any particular substance, the great range in values would make it impossible to set the greater part of the lines in juxtaposition on the two sets of plates at the same time. Therefore, the juxtaposition of most lines indicates that the effect is too small to be observable in those cases. For the weak lines, the effect being a function of the emission, the displacement should be small and probably smaller than I could detect. On account of the width of many of the *p*- components it would escape detection at any rate. Again, any irregular contraction of the films in drying would cause appreciable error in the measurement of very small quantities. Errors from such sources are mitigated by taking several sets of plates. Two sets of *s*- and *p*- plates were at my command, but only one set of no-field plates. When irregularities were present upon one set of plates they were also present upon the other, but the difficulty might be with the no-field plate with which they were compared. For the purpose of detecting small variations, then, the method is not altogether free from error. But if both *s*- and *p*- components are photographed together, i. e., without the intervening calcite, neither does one then know whether the *p*- component or the *s*- components are displaced in an unsymmetrical triplet; and if the *p*- component happens to be a wide line and the *s*- components have small separations, the readings are then confusing and much less accurate than the method which I have followed. Had I anticipated the dissymmetry of lines at the time

[1] *Physikalische Zeitschrift*, **9**, 123, 1908, Equation 11.

[2] *Annalen der Physik*, **24**, 597, 1907.

these pnotographs were taken, I should have desired to have photographed the *p*- and *s*- components directly upon the same plate as the no-field lines by either the well-known method of Rowland or of Runge. Even then, it occurs to me that this procedure might not be accurate enough to test dissymmetries as small as one might expect from the Voigt equation, as it also seems to me that the method is not quite accurate enough to test quadruplets and triplets for simple relationship between the magnitudes of the separations. For instance, are these separations related to a normal "*a*," and are they multiples of aliquot parts of "*a*"? My previously measured triplets would certainly not suggest the choice of any value as a normal, and neither would the quadruplets in the present investigation. The question, however, does arise, "Is there adequate error, to allow one to collect them into groups whose separations are related to one another in a simple way?" I do not think the error so large. However, it does seem to me what is wanted to answer this interesting question, and the dissymmetry question as well, from the standpoint of Voigt's equation, is an experimental method of five times the accuracy, which one may possibly obtain with some of the new forms of interferometer. Such a method was used by Gmelin (*Physikalische Zeitschrift*, **9**, 212, 1908) who found the mercury line λ 5790 to have a dissymmetry proportional to the square of the field-strength. Zeeman (*Science Abstracts*, **12**, 155, 1909) has recently confirmed the results of Gmelin.

This results from the hypothesis of linkages among the electrons (Voigt, *Physikalische Zeitschrift*, **9**, 353, 1908). The field-strength of the two sets of plates here studied differed only by 20 per cent., and were not adapted to an investigation of that point like Gmelin's observations, whose field-strength varied two and one-half fold. However, the following considerations will show that my measurements should have given me some intimation of such a change with the change in field-strength. If one designates the distances of the two *s*- components from the null position by "*a*" and "*b*," the distance from the middle is $\frac{(a+b)}{2}$, and the deviation of the apparent middle is $\frac{(a-b)}{2}$. For a 20 per cent. greater field, on the assump-

tion of Gmelin, the former is increased 1.2 times, and the latter $(1.2)^2$ times. The weaker of my dissymmetrical lines were measurable only upon one set of plates, but those lines which could be measured upon both sets of plates gave practically the same results when the separations of the weaker field were increased 1.2 times. It would not seem that all of the difference for all of the lines was due to experimental error. If the result is granted, it would mean that the dissymmetry is proportional to the field-strength. However, greater variation in field-strength would be more competent to settle the question. From the Voigt equation the above half sum is also the usual separation and the half difference the dissymmetry. The latter value is a constant and is independent of the field-strength. Now there are cases in thorium where $a=3b$, and therefore the magnitude of the dissymmetry is b. Maintain this value of b constant and diminish the field one-half. The distance from the apparent middle is then $\frac{(a+b)}{4}$ which equals b. One component then falls in the null position, and only the other component is displaced. This is meaningless, and 20 per cent. difference in field should have given me something different from what was observed if there was any constancy in the value $\frac{(a-b)}{2}$. Therefore, there seems some reason to assume that the dissymmetries are due to some other causes than those discussed in Voigt's equations. Voigt rather looked for dissymmetries when the field-strength was weak. This has been recently signally confirmed by H. Nagaoka and S. Amino (*Science Abstracts*, **12**, 155, 1909). They find a few unsymmetrical lines, with the red component stronger and least displaced. These displacements plotted against the magnetic field gave the theoretical hyperbola. But beyond 5000 Gauss, which is only one-fourth of the weakest field used here, the separation is proportional to field-strength and the intensities of the opposite components equal.

Dissymmetry has also been observed by Mr. Jack (Zeeman, *Physikalische Zeitschrift*, **9**, 343, 1908). His spectrograms were taken partly prior and partly subsequent to these thorium spectrograms and with the same apparatus. Professor Voigt writes me that Mr. Jack thinks he has traced the dissymmetry to changes in the azimuth of

the polarized beam of light incident upon the grating. This is important if true. I think that two experimental facts make it implausible in thorium. First, a number of the observed dissymmetries are too large. Second, before placing the plates in the camera for an exposure the quartz condensing lens was often shifted and readjusted to see that there was the best possible illumination of the grating. (But the lens was never moved during an exposure.) It does not seem probable that this lens occupied the same position throughout the thorium exposures or even the greater part of them. Consequently any point on the grating was illuminated at different times by light in a different azimuth. If the effect had been appreciable, it would have produced inconsistencies in my measurements which I have not observed. Purvis (*Proc. Camb. Phil. Soc.*, **15,** Part I, 45) records a displacement of several lines in the magnetic field toward the red. I had suspected such a change when watching lines under the microscope while an assistant turned the magnetic field current on and off, but had not followed it up with quantitative measurements. This could scarcely be identical with the results of Jack (*loc. cit.*). It would seem, rather, to be analogous to a pressure-shift of the lines.

In my previous investigation (*loc. cit.*) the *p*- and *s*- components were measured on independent plates. Small dissymmetries would have remained undiscovered. It should be said, however, that for these substances I had plates with both *p*- and *s*- components thereon, i. e., plates photographed without the intervening calcite. As I passed from line to line comparing the intensities of the *p*- and *s*- components, some of the pronounced dissymmetries herein recorded would have been glaringly conspicuous without measurements. Further, the dissymmetries are not only often large but they are found also in lines having more than three components, up to and including a line of nine components. In these also may be found multiple relationships among the unsymmetrical components, which could be only a coincidence unless these dissymmetries were proportional to the field-strength. Thorium was also photographed without the intervening calcite, but the components were too entangled and bewildering to be of any service and the plates were not saved. This resulted in some loss in comparing the intensities of the *s*- and *p*-

components. The relative intensities of the *s*- and *p*- exposures can therefore only be roughly approximated. To obtain an accurate basis of comparison, the *p*- intensities may need to be reduced about 25 per cent. The intensities here recorded are multiples of apparent brightness of the components in the first-order spectrum, taking a line which is just sufficiently defined to be continuous latterly across the plate as unit intensity.

In the dissymmetry theory there is a dissymmetry in the intensity of the components. The component which has a smaller displacement than its companion should have greater intensity. In Mr. Jack's lines reported by Zeeman (*loc. cit.*) there is no such inequality recorded. In thorium the least displaced component is always the stronger. There are a few apparent exceptions, but these are invariably due to overlapping components of adjacent lines. However, there are a large number of lines which show this dissymmetry in intensity for which there was no dissymmetry in separation. Some of these, again, are plainly overlaps, but there are a great many which are not. Further, there are cases where components are broader than their conjugate components. No accurate record could be made of this, for the effect might be slight or large. Sometimes it was the red, sometimes the blue component, which was widened. It seemed possible that one might have here components of two very close lines whose separations differed but little in magnitude. The width of some of the undisturbed *p*- components sometimes suggested the same thing. But the latter might be close doublets which would separate with stronger fields. The no-field plates actually showed many of these to be two lines. A no-field line shaded to one side might suggest the presence of other lines also, but this is too common an occurrence with spectral lines to be definite. If one could omit all of these there were still lines which showed this action for sharp no-field lines. It might appear that the broadened line was going to separate into two lines with stronger field, leaving an unequal number of components on the two sides of the zero position. One could only answer this possibility by photographing with very strong fields. It is not implausible, because there are cases found in thorium where the number of components on the two sides of the zero position do not balance. One component of one line which is unseparated

for the weaker field-strength is double for the 20 per cent. stronger field. That it is such a splitting is certain because the mean of the two separations is symmetrical with the separation of the opposite component.

In one small region of the spectrum (Table XIX) I found it necessary to make accurate measurements of wave-length, from line to line, to assure the identification. I have recorded these lines as measured, although Exner and Haschek's tables are more accurate than my measurements. However, lines are often shifted by small amounts, and these lines were peculiar in other respects (see discussion, Table XIX). Hence there might be cause for the shift, and I have, therefore, not hesitated to record them as read. There can, in general, be no question as to the identity of these lines, unless it be for lines not given in Exner and Haschek's tables. There were many of the latter, and it may be an error to call them all thorium. Many of them possess peculiarities in common with lines which are certainly thorium in the list. There was no special effort made to find impurities but lines due to calcium, iron, strontium, and lead are present and none of these impurities behaves peculiarly. Some of the strong lines of Exner and Haschek's tables are omitted because of their weakness, but they are generally omitted because of the confusion due to overlapping components of other lines, leaving the components a blurred mass.

The following abbreviations have been used: *s*- and *p*-, as already explained; *r*, red; *b*, blue; λ, wave-length; *d* or *diff.*, diffuse; *O*, order; *o*, overlap; *i*, intensity; "*a*," normal separation; *A*, approximate separation; $\Delta\lambda/\lambda^2$, change in wave-frequency per cm, and therefore a positive value means a displacement toward the blue end of the spectrum. The normal separation corresponds to a value of 1.105 for a field-intensity of 24,450 lines to the square cm, used in my previous contribution and checked here from the separation of the calcium lines. If the strength of field is in error, corrections may be made if needed when physicists are decided upon the accuracy and magnitude of these magnetic fields.

GENERAL DESCRIPTION OF THE TABULATED MEASUREMENTS

Tables I–XI inclusive contain symmetrical lines exclusive of the triplets.

Table I consists of two 14-component lines. The interior *s*-components are too weak to be very positive of their presence. The exterior *s*- components are diffuse, and not capable of measurement with desirable accuracy. The *p*- components agree very closely for the two lines. This fact, and the general appearance of the components, leads to the conclusion that they are duplicates. The separations are shown as multiples of 0.17, and these agree as closely

TABLE I

λ 4282.20			λ 4116.91		
i	$\Delta\lambda/\lambda^2$	A	*i*	$\Delta\lambda/\lambda^2$	A
5.....	(—2.26) *s*	(14×.17)	7.....	—2.37 *s*	(14×.17)
1—.....	.... *s*		1—....	—.... *s*	
1—.....	.... *s*		1—....	—.... *s*	
1—.....	—1.22 *p*	(7×.17)	1.....	—1 19 *p*	(7×.17)
1.....	— .87 *p*	(5×.17)	2.....	— .86 *p*	(5×.17)
2—.....	— .54 *p*	(3×.17)	3.....	— .50 *p*	(3×.17)
2.....	— .17 *p*	(1×.17)	3.....	— .17 *p*	(1×.17)
2.....	+ .17 *p*		3.....	— .17 *p*	
2.....	+ .51 *p*		3.....	+ .51 *p*	
1.....	+ .86 *p*		2.....	+ .85 *p*	
1.....	+1.22 *p*		1.....	+1.20 *p*	
.....	+.... *s*		1—....	+.... *s*	
.....	+.... *s*		1—....	+.... *s*	
5.....	(+2.26) *s*		7.....	+2.37 *s*	

TABLE II

λ 4086.71			λ 4019.30		
i	$\Delta\lambda/\lambda^2$	A	*i*	$\Delta\lambda/\lambda^2$	A
5.....	+ 2.83 *s*	13×.214	5.....	+1.99 *s*	?
3.....	+ 1.95 *s*	9	3.....	+1.45 *s*	
4.....	+ 1.25 *p*	6	1+....	+ .89 *s*	
1.....	+(1.05) *s*	5	8.....	+ .80 *p*	
5.....	+ .42 *p*	2	1.....	+ .40 *s*	
1—.....	+(.16) *s*	?	6.....	+ .35 *p*	
1—.....	—(.16) *s*	?	6.....	— .34 *p*	
5.....	— .41 *p*	4×*a*/11	.....	+....*s*	
1.....	—(1.05) *s*	10	8.. ..	+ .80 *p*	
3.....	— 1.26 *p*	13	.....	+....*s*	
3.....	— 1.95 *s*	19	.....	+....*s*	
4.....	— 2.83 *s*	28	5.....	+1.99 *s*	

TABLE III

λ 4142.87			λ 3434.09		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
1.....	−2.25 *p*	10×.226	2.....	−2.36 *s*	7×0.34
5.....	−1.35 *p*	6	1—....	— ... *s*	
2.....	−1.34 *s*	6	3.....	−1.04 *p*	3
1.....	−0.68 *s*	3	1—....	— ... *s*	
1+.....	−0.47 *p*	2	4.....	−0.34 *p*	1
1.....	0.00 *s*		1—....	... *s*	0 ?
1..	+0.47 *p*		4.....	+0.34 *p*	
.....	+0... *s*	0	1—....	*s*	
2.....	+1.32 *s*		3.....	+1.0 *p*	
.....	+1.35 *p*	0	1—....	*s*	
1.....	+2.36 *p*		2.....	+2.36 *s*	

TABLE IV

λ 4094.99			λ 3929.74		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
1+.....	−1.51 *s*	?	3.....	−1.01 *s*	?
2+.....	−0.92 *s*		4.....	−0.84 *p*	
10.....	−0.78 *p*		1.....	−0.73 *s*	
1+.....	−0.41 *s*		5.. ..	−0.27 *p*	
1.....	−0.36 *p*		1—...	— ... *s*	
1.....	+0.36 *p*		.....	+ ... *s*	
1+.....	+0.41 *s*		5.....	+0.28 *p*	
10.....	+0.78 *p*		.....	+ ... *s*	*sb* diffuse
2.....	+0.96 *s*		3.....	+0.83 *p*	
1.....	+1.51 *s*		.....	+ ... *s*	

TABLE V

λ 3704.16		
i	Δλ/λ²	A
1.....	−2.08 *s*	?
1.....	−1.33 *s*	
1.....	−0.70 *p*	
1.....	−0.56 *s*	
1+.....	0.00 *p*	
1.....	+0.57 *s*	
2.....	+0.73 *p*	
.....	+ ... *s*	diffuse
.....	+ ... *s*	diffuse

TABLE VI

λ 4277.49			λ 4180.15		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
1.....	−1.50 *s*	?	5.....	− ... *s*	Brd. poss.
2.....	−0.97 *s*		3.....	−1.44 *p*	2 or 3
12.....	−0.70 *p*		1.....	−1.08 *p*	comps.
1.....	−0.46 *s*		1−....	−(?) *p*	
1.	+0.46 *s*		1−....	+(?) *p*	
10.....	+0.70 *p*		1.....	+1.09 *p*	
2.....	+0.99 *s*		3.....	+1.44 *p*	
1.....	+1.50 *s*		.....	+ ... *s*	0

λ 3649.90		
i	Δλ/λ²	A
1+.....	−2.86 *s*	?
1−.....	− ... *s*	
1.....	−1.20 *p*	
2.....	0.00 *ps*	
1−.....	+1.20 *p*	
.....	+ ... *s*	
1+.....	+2.86 *s*	

TABLE VII

λ 3792.52		
i	Δλ/λ²	A
3.....	−1.94 *s*	?
1.....	−1.33 *p*	
1.....	−1.05 *s*	
12.....	0.00 *p*	
1.....	... *s*	
1.....	+1.33 *p*	
3.....	+1.94 *s*	

TABLE VIII

λ 4448.00		λ 4202.02		λ 4182.15*	
i	$\Delta\lambda/\lambda^2$	*i*	$\Delta\lambda/\lambda^2$	*i*	$\Delta\lambda/\lambda^2$
1+...	−1.82 *s*	1−....	−0.84 *p*	.....	− ?
6.....	−0.77 *s*	4.....	−0.69 *s*	6.....	−1.10 *s*
10.....	−0.55 *p*	2.....	−0.27 *p*	10.....	−0.79 *p*
8.....	+0.56 *p*	2.....	+0.28 *p*	8.....	+0.79 *p*
5.....	+0.76 *s*	4.....	+0.69 *s*	4.....	+1.11 *s*
1.....	+1.87 *s*	1.....	+0.83 *p*	.....	+ ? *s*

*The external pair of components may belong to other lines, which would leave this line a quadruplet.

λ 4178.20		λ 4069.40		λ 3549.83	
i	$\Delta\lambda/\lambda^2$	*i*	$\Delta\lambda/\lambda^2$	*i*	$\Delta\lambda/\lambda^2$
3.....	−1.06 *s*	8.....	−1.22 *s*	1+...	−1.92 *s*
10.....	−0.78 *p*	2.....	−0.50 *p*	1.....	−0.83 *s*
1.....	−0.52 *p*	4.....	−0.18 *p*	6.....	−0.60 *p*
1.....	+0.52 *p*	4.....	+0.18 *p*	5.....	+0.60 *p*
10.....	+0.78 *p*	3.....	+0.50 *p*	1.....	+0.83 *s*
3.....	+1.06 *s*	8.....	+1.23 *s*	1.....	+1.92 *s*

λ 3338.00*	
i	$\Delta\lambda/\lambda^2$
6.....	−1.81 *s*
1.....	−0.89 *p*
1+....	−0.36 *p*
1+....	+0.32 *p*
1.....	+0.90 *p*
6.....	+1.80 *s*

*The *p*-components are measured in the second order and *s*-components in the first order.

TABLE IX

λ 4624.22		λ 4499.13*		λ 4369.50†	
i	$\Delta\lambda/\lambda^2$	*i*	$\Delta\lambda/\lambda^2$	*i*	$\Delta\lambda/\lambda^2$
1—....	—(1.89) *s*	1.....	—(1.53) *s*	2.....	—2.07 *s*
2.....	— 0.41 *p*	1+....	—(0.43) *p*	1.....	—0.98 *p*
3.....	0.00 *p*	2.....	0.00 *p*	5.....	0.00 *p*
2.....	+ 0.41 *p*	1.....	+(0.43) *p*	1.....	+0.98 *p*
1—....	+ 1.89 *s*	1.....	+(1.89) *s*	2.....	+2.07 *s*

* The *s*- are diffuse inward and probably other components are present.
† The *s*- are diffuse and the *p*- have diffuse background.

λ 3892.40		λ 3872.51 *		λ 3842.10†	
i	$\Delta\lambda/\lambda^2$	*i*	$\Delta\lambda/\lambda^2$	*i*	$\Delta\lambda/\lambda^2$
1.....	—1.91 *s*	.....	— *s*	12....	1.75 *s*
4.....	—0.66 *p*	.....	— *p*	2....	1.38 *p*
5.....	0.00 *p*	1.....	0.00 *p*	30....	0.00 *p*
3.....	+0.66 *p*	5.....	0.57 *p*	1+..	1.40 *p*
1.....	+1.91 *s*	3.....	1.30 *s*	12....	1.75 *s*

* *pr* and *sr* are overlapped.
† The middle *p*- may be double.

λ 3589.47*	
i	$\Delta\lambda/\lambda^2$
.....	— ...
1.....	—0.55 *p*
1+....	0.00 *p*
1.....	+0.57 *p*
.....	+ ... *s*

* The *s*- are both overlapped.

TABLE X

λ	*i*	Δλ/λ²	REMARKS	λ	*i*	Δλ/λ²	REMARKS
4689.33	1+, 1	.67		4357.79	2	1.29	
	2 , 1	.29			3	.80	
12.06	1	1.14		44.50	5 , 6	1.13	
	2 , 1+	1.07			10 , 12	.59	
03.05	1 , 1—	1.03		34.11	2	1.35	
	2 , 1+	.59			3	.67	
4540.60	1+, 2	1.04		32.09	1+, 2	1.18	
	5	.55			3 , 2	.42	
31.90	1+, 2	1.18		28.86	3	1.25	*sr o*
	4 , 5	.55			3 , 2	.34	
4493.57	2	1.00		27.30	1 , 2	1.09	
	6 , 5	.86			1 , 2	.43	
92.02	1	(1.24)		10.19	3	1.18	*
	1+, 1+	(.28)			4 , 2	.19	
74.25	2	1.25		4297.53	1 , 1+	1.23	
	5 , 4	.53			2 , 3	.64	
58.17	1 , 1+	.86		78 50	1+	.96	
	5 , 3	.55			2 , 1+	.49	
39.26	7 , 8	1.04	*sb* probably *o*	74.19	4	.83	*sr o*
	12 , 10	.59			4	.42	
36.40	10 , 1+	(.96)	*sr o*	67.68	1+, 1	(1.81)	
	2 , 2	.96			4 , 2	.79	*pr* probably *o*
26.18	2	1.35		65.27	1	(1.60)	
	5 , 3	.49			2 , 3	1.54	
09.10	2	1.27		56.25	2	.65	
	3 , 2	.49			2	.42	
01.87	2	1.50		33.41	4	1.30	
	4 , 5	1.22			6 , 4	.71	
4374.08	4 , 4	1.18	*pr o* by 4.33	29.58	4	1.29	
	8 , 4	.56			8	.94	

TABLE X—CONTINUED

λ	*i*	Δλ/λ²	REMARKS	λ	*i*	Δλ/λ²	REMARKS
4195.04	1 ,	(1.48)		4085.22	8	1.13	
	1+, 1—	(.91)			15	.78	
88.75	1	(1.72)		77.89	1—, 1+	(1.29)	
	1	(1.08)			3	.28	
82.15	6 , 4	1.11		68.15	1	(2.14)	
	10 , 8	.79			1 , 2	(1.14)	
72.52	6	1.32		55.00	1	(1.76)	
	3 , 2+	.15	*p* 2d *O*		1	(.59)	
68.81	1	(1.16)		53.68	1	(1.30)	
	3	.61	2d *O*		3 , 4	1.06	
48.35	5	.73		41.36	2	1.18	
	5 , 4	.19	2d *O*		6 , 5	(.13)	2d *O*
40.42	5 , 3	1.16		32.69	2 , 5	(.66)	*sb o*
	5	.20	2d *O*		8 , 5	(.90)	*pr o*
36.53	3 , 3	1.33		41.00	5 , 4	1.20	
	4 , 5	.85			4 , 5	.40	*p* 2d *O*
32.95	8 , 7	1.08		29.13	.. ..	(1.13)	*s o*
	12 , 10	(.12)	2d *O*		2	(.24)	
31.60	3	1.25		27.82	1	(1.23)	
	4 , 5	.36	*p* 2d *O*		2	.50	
31.20	2	1.27		26.30	3 , 2	1.21	
	1 , 1+	.19	*p* 2d *O*		2	.26	
23.72	4 , 3	1.28		17.65	1+	(1.06)	
	1 , 1+	(.25)	*p* 2d *O*		2	.56	
08.61	8	1.03		01.22	1	(1.10)	
	10 , 12	.33	2d *O*		3	.83	
04.60	4	1.33	†	3982.23	1 , 2+	1.27	*sb o, pb o*
	3	.82	*p* 2d *O*		3 , 4	1.42	*p*>*s*
4093.60	5 , 4	1.17		81.28	6 , 8	1.36	possibly each
	1	(.17)	*p* 2d *O*		10	.78	*s*-doublet

TABLE X—CONTINUED

λ	*i*	Δλ/λ²	REMARKS	λ	*i*	Δλ/λ²	REMARKS
3979.20	2 , 3	1.20		3832.87	.. 2	+1.28	*r* components
	4 , 3	.76			.. 2	+ .65	lost in 3.10
74.38	1+	1.35		30.70	.. 1+	(+1.33)	*r* components lost
	4 , 3	.67			.. 3	+1.31	in 0.93 *p*=*s*
67.52	2 , 3	1.26	*p* possibly unsymmetrical	21.57	4 , 3	1.00	
	6 , 4	.32	*p* 2d *O*		8 , 6	.36	2d *O*
64.96	1	(1.27)		02.65	1	(.64)	
	2	.30			1	(.65)	*p*=*s*
63.33	2	1.26		3773.94	2 . 3	1.06	*sb o*
	3	.72			6 , 5	.33	2d *O*
57.24	1+, 1	(1.32)		63.04	6	.80	
	2+, 2	.60			2	.63	2d *O*
37.14	8 , 8	1.07	‡	50.82	1 , 1+	1.18	
	10 , 8	.53			3	1.14	*p*=*s*
51.25	.. 1	(+2.10)		47.73	8	1.04	
	1 , 3	.41			12	(.24)	2d *O*
13.95	1	(.95)		46.68	1	(.98)	
	2+, 2	.67			1	(.59)	
12.41	3	1.18		41.40	20	1.15	
	4 , 3	.45	2d *O*		30	.39	2d *O dr*
08.03	1+, 1	(1.33)		31.60	3	1.41	
	2 , 1+	.98			2 , 3	.47	
00.25	1+, 2	1.41		30.92	5	1.28	*s* broad possibly
	1+, 2	.45			8	.54	double 2d *O*
3894.53	1	1.50		28.04	2	1.30	
	1+	.84			3	.50	
59.98	10 , 12	1.19		20.52	2 , 6	(1.18)	*sb o*
	8 , 6	.38	2d *O*		7	.64	
58.72	2	.50		18.02	5 , 3	(1.46)	*s*, 1st *O sr o*
	1	(.60)	*p*>*s*		2 , 1	(.20)	*p* 2d *O*

TABLE X—CONTINUED

λ	*i*	Δλ/λ²	REMARKS	λ	*i*	Δλ/λ²	REMARKS
3707.60	1 , 1+	(1.79)		3642.41	4 , 5	1.13	
	2	1.29			4 , 3	.72	*p* 2d *O*
00.95	8	1.23		39.55	5 , 3	.79	§
	2+, 3	.63			7 , 5	.40	2d *O*
3698.47	1	.41		21.25	8	1.02	
	1+, 2	.38	Probably *p*=*s*		8 , 6	.20	2d *O*
98.30	.. 1	(+1.34)	*sr o*	20.52	1	1.32	
	3	.84			3 , 2	.32	2d *O*
94.08	6 , 10	1.31		15.26	10 , 8	1.30	
	12 , 8	.69			8 , 6	.20	2d *O*
90.67	3	1.26		14.16	1+, 2	1.06	
	5 , 3	.50			5 , 3	.33	2d *O*
87.80	1+	(1.11)		12.57	2	1.08	
	1—, 1	(.30)	*p* 2d *O*		6 , 5	.75	
70.12	2	.52		07.52	1 , 1+	1.33	
	2	.57	Probably *p*=*s*		2	.66	
67.13	1—, 1	(1.43)		3598.31	6 , 5	.87	
	2	.86			2	(.18)	*p* 2d *O*
65.90	1+	1.03		92.92	7 , 5	1.16	
	2	.47			1+, 2	.29	*p* 2d *O*
62.80	1	(1.69)		82.15	8 , 10	1.29	
	1+	.71			5 , 3	.20	*p* 2d *O*
62.36	1	(1.38)		72.52	2	1.19	
	1+	.83			5 , 3	.33	2d *O*
59 66	8	1.26	2d *O*	59.55	4	1.98	
	15 , 12	.62	*pr o*		6 , 5	.38	2d *O*
52.31	.. 5	+1.18	*sr O*	16.96	3 , 2	1.40	
	12 , 10	.63			5 , 3	.67	
47.75	4 , ..	(1.31)		16.50	3	1.16	
	12 , 10	1.00			1	(.24)	*p* 2d *O*

TABLE X—CONTINUED

λ	i	$\Delta\lambda/\lambda^2$	REMARKS
3514.70	5	1.18	
	2 , 1+	.29	p 2d O
13.38	1	(1.33)	
	1	(.63)	
09.33	1	(1 19)	2d O
	1 , 3	(.70)	‖
00.70	1 2	(1.52)	
	2 , 1+	(.65)	
00.15	3	1.55	
	7 , 5	.86	
3499.15	3 , 2	1.28	
	5 , 4	.70	
97.41	1	(1.19)	
	1+	(1.48)	
73.21	1+, 3	1.42	‖
	3	.60	
71.40	1+	1.36	
	3	.74	
70.08	7	1.29	
	15	.55	2d O
65.88	12	.93	2d O
	15 , 12	.88	Probably p=s
54.83	1	(1.30)	
	2	.51	
54.35	1	(1.19)	
	3	.33	
52.81	6	1.75	
	4 , 3	.63	p 2d O
49.77	5	1.22	
	3	.69	p 2d O
3445.87	3 , 2	1.07	
	5 , 3	.54	
41.16	2	1.30	
	2	.51	p 2d O
39 07	3	1.30	
	5 , 4	.33	2d O
25.28	4 , 3	1.18	
	3	(.57)	
19.29	2 , 3	1.29	
	6 , 5	.50	2d O
14.59	1+	.91	
	4 , 3	1.04	p>s
11.92	4	1.05	
	1	.38	p 2d O
09.37	4	1.08	
	2 , 1+	.36	p 2d O
08.76	3	1.33	
	2 , 1	.38	p 2d O
3395.50	2	1.16	
	2 , 1+	.68	
89.77	3 , 2	.93	¶
	5 , 4	.86	
86.64	1	1.31	2d O
	4 , 3	.75	
79.84	1	(1.15)	
	1	(.45)	
78 70	2 , 2+	1.39	2d O
	4 , 3	.34	
67.93	3 , 2	1.01	
	5 , 2	.26	2d O

TABLE X—CONCLUDED

λ	i	$\Delta\lambda/\lambda^2$	REMARKS	λ	i	$\Delta\lambda/\lambda^2$	REMARKS
3364.79	4	1.45		3290.25	2 , 1+	1.33	
	3 , 2+	.61	*p* 2d *O*		2 , 1+	.07	*p* 2d *O*
55.38	1+, ..	(—.94)		86.71	4	1.71	
	2 , 3	1.05			3 , 2+	(.18)	*p* 2d *O*
49.10	5	1.26		67.14	1+, 3	1.30	
	1	.30	*p* 2d *O*		3	.85	
48.93	2	.78		45.91	5 , 4	1.46	
	1	.28	*p* 2d *O*		3 , 2	.61	*p* 2d *O*
47.72	1	(1.68)		25.51	2	1.28	
	1	(.89)			3 , 2+	.37	*p* 2d *O*
35.17	2	(1.34)		13.71	1+	(.84)	
	1	(.61)	*p* 2d *O*		1 , 1+	(.48)	*p* 2d *O*
34.72	3	(1.34)		3150.56	3 , 2	1.34	
	8 , 7	.67	*p* 2d *O*		1+, 1	(.35)	*p* 2d *O*
24.88	1+	.83					
	5 , 4	.35	2d *O*				

*The line does not appear on no-field plates, but comparison of *s*- and *p*- plates *pr* lies almost in the middle and the deviation largely due to the *pb* component. It might be another line.

†The *s*-components of this line are broad, and each may consist of three.

‡The *p*- and *s*- are in the ratio of 1 to 2. The *s*- is like its companion triplet line 3938.01. The magnitude of the separation suggests the normal triplet 1.11. A retest was made since these were easily measured lines, but it was not possible to increase the value 1.07; if anything, the value is a trifle smaller.

§The second order no-field line is just off the plate. In the first order the lines show dissymmetry, but are too thick to measure. The line is probably unsymmetrical.

‖This line does not show on no-field plate. When the *p*-components are compared with the *s*-components they do not appear symmetrical.

¶Juxtaposition of *p*- and *s*-plates shows that the measured difference in the value of *p*- and *s*- is actually present and not an error of measurement.

as could be expected for the *p*- components. The value 0.17 does not appear to be an aliquot part of the normal "*a*," for $a/6$ gives 0.184 and $a/7$, 0.158.

Table II contains two 12-component lines, which are evidently not related. The components of λ 4086.71 are related in a simple way. All are probably multiples of 0.214. This differs little from $3a/16$, which is not an aliquot part of "*a*." The readings may also be represented about as well by multiples of $a/11$, which is one of Runge's aliquots of "*a*." The former value gives a distance from component to component for the *s*- separations of 4×0.214, and the same value for the *p*- components. The latter, $a/11$, gives uniform spacings for the *s*- components; but for the *p*- components we have $8a/11$ once, and $9a/11$ twice for the spacings. There can be scarcely a doubt but that the components are equally spaced and that the value is the same for both *s*- and *p*-. This leads to the rejection of the aliquot interval value, $a/11$.

Table III gives two 11-component lines. They are not duplicates, but a multiple relationship holds for the components of each line. The repeated values are not rational parts of "*a*."

Table IV contains two 10-component lines. They are not duplicates and a simple multiple relationship in the components is not apparent.

Table V has one 9-component line. The inner pair of *s*- components is $a/2$ but the other components are not related to it.

Table VI has three 8-component lines and all differ. A multiple relationship of the components is not apparent.

Table VII contains one 7-component line.

Table VIII contains seven 6-component lines. There are no duplicates, and there are only three separations in the different lines which correspond to "*a*" or multiple aliquot parts thereof. For line λ 4178.2 the components are (4, 3, 2) times 0.262 with deviations respectively of +0.012, −0.006, and −0.004. While (4, 3, 2) times $a/4$ would give deviations of −0.05, −0.05, and −0.03 respectively. Such deviations in a set of readings is certainly exclusive.

Table IX contains seven 5-component lines and no duplicates.

Table X contains one hundred and sixty-six quadruplets. The

first row gives the *s*-, and the second the *p*- components. Each separation represents both a positive and a negative value. Under intensities the first recorded refers to the red, the second to the blue component. If the components are of equal intensities only one value is recorded. It overlaps the intensity, of course, arises from the red component of one, and the blue component of the other line. There are several duplicates, but among these duplicates I have found no series. It is difficult to tell just when these lines may be duplicates. They shade off by small values toward separations which are quite different. In the triplets of yttrium and zirconium I found the values to progress by almost insensible increments from very small to very large separations, and if there were distinct types there was no separating them. The thorium quadruplets behave in the same way, particularly if one includes the unsymmetrical quadruplets. The quadruplets, however, have a *p*- as well as an *s*- separation, which gives one a double chance to isolate types. We may choose, e. g., the *p*- separation equal to $a/2$ (.553) and find it represented in lines λ 4017.65, 3730.12, 3670.12, 3470.08, 3445.87, and 3324.88. The corresponding *s*- separations for these lines are respectively 1.06, 1.28, .52, 1.29, 1.07, and 0.83. Here are evidently two pairs. The value 0.83 ($=3a/4$) is the only one related to "*a*." Similarly if one were to choose lines corresponding to either of these *s*- separations, one would find the *p*- components to have as great a variety in their separations. There are a number of the *s*- separations reasonably near to the value "*a*," but very few, however, of the corresponding *p*- components come near to aliquot parts of "*a*." These relations suggest that there is no particular meaning to be attached to a "normal" separation among these quadruplets. None of these separations approaches reasonably near to the quadruplet principal series, neither were there representatives of the companion sextuplet series. There are lines having the *s*-, and other lines having the *p*-, separation of the same magnitude as the quadruplet principal series, but no lines having both components coincidentally.

Table XI contains a list of sixty *p*- doublets. The intensities follow the order of Table X. The weakest of these lines do not appear upon the *s*- plates, and only upon one set of *p*- plates. On account of overlapping, it was impossible to make out the character of the

separations for some *s*- components, and impossible to measure others. Some *s*- components were too diffuse to measure. It is safe to say that most of these lines are quadruplets. On account of

TABLE XI

λ	*i*	Δλ/λ²	REMARKS
4740.72	4	1.14	*s* broad, apparently not separated, possibly double
4612.71	1	.32	
4588.40	3	.52	6 components
4472.47	1 , 2	.31	
69.75	2 , 1	.31	
02.59	1+, 1	.79	
4388.59	1 , 1+	1.19	Probably *p* > *s*
87.27	2 , 1	(.71)	
61 91	2+, 2	.76	
02.25	2 , 1+	.62	
4256.42	2	(.51)	
47.73	1 , 2	(.66)	
37.25	1+, 2	(.84)	
35.59	2	1.41	
17.37	1+, 2	1.38	
4166.70	1+	(1—.90)	
	1	(+1.13)	
4158.71	3	(—.17)	
	2	(1+.22)	
4107.41	2	1.31	
4087.46	1	(.50)	
70.86	1+, 1	.37	
45.74	1	(1.23)	
29.80	3	.66	
16.48	2	1.04	
03.21	.. 4	+.30	Quadruplet *sr* and *pr* lost in 03.39
3969.15	1+	(.51)	
81.70	1	.80	
53.53	2	.49	
52.60	1	.41	
45.96	3	.58	
45.27	2	.56	
42.95	2	1.44	
42.75	2	1.01	
3937.14	4 , 3	.51	2d *O*, *s o*
36.07	1+, 1	.57	
12.05	1—, 1+	.50	
3698.47	2	.40	
86.03	1	1.01	
76.88	1+, 1	.62	
75.05	2	1.60	
58.32	1+, ..	—.64	*o* 8.20
58.20	.. 3	+.47	
50.75	3	.73	
48 28	1	.54	
24.57	1	.89	
06.32	1—, 1+	.90	
3556.45	1+	1.00	

TABLE XI—CONCLUDED

λ	i	$\Delta\lambda/\lambda^2$	REMARKS
3516.96	5 , 3	.67	
3406.35	1 , 1—	(.36)	
3385.16	1	(1.26)	$p>s$
3295.44	1+, 1	.50	
62.79	8	1.29	2d *O* *
48.62	1 , 2	.80	2d *O*
3193.29	2 , 1	.54	2d *O*
90.25	3 , 2	.81	2d *O*
42.76	2	.77	1st *O*
24.47	3 , 2	.84	2d *O*
17.75	1	(.53)	2d *O*
10.12	2 , 1	.83	2d *O*
3035.21	1	(.32)	2d *O*
02.51	1	.53	2d *O*

*The *s*- is very peculiar. It is spread over a field about 40 per cent wider than the *p*- separation.

the wide variation in the magnitude of these *p*- separations it would be no easier to arrange and classify them than in a similar number of triplets. If one may add the greater portion of them to the quadruplets, they increase the already large variation of these components and make it more improbable that there is any standard in the magnitudes of these separations.

[*To be continued*]

Minor Contributions and Notes

ON THE SPECTRUM OF THE *ANDROMEDA* NEBULA

Lest some readers of Professor Scheiner's note in the last number of this *Journal* (**30**, 69) may hold the impression that I failed to do justice to his observations on the spectrum of the *Andromeda* nebula I request permission to quote herewith from the second paragraph of my paper (*Lick Observatory Bulletin*, **5**, 71, 1909):

> There are but two published observations, as far as known, which cast any doubt on the continuous character of the spectra of spiral nebulae: one by Scheiner (*Astronomische Nachrichten*, **148**, 325, 1899) and the other by Huggins (*Atlas of Representative Stellar Spectra*, p. 119, 1899), both of whom worked on the *Andromeda* nebula. Each of these observers obtained a spectrogram showing absorption lines: the former, lines corresponding to G (λ 4308) and H (λ 3969) of the solar spectrum; the latter, the G, H, and K (λ 3934) lines, with some others not named. The spectrogram by Scheiner was probably faint and there may be some doubt as to its interpretation, for the late Director Vogel, who presumably saw the plate, when revising Newcomb-Englemann's *Populäre Astronomie* several years later, said on p. 577: "Selbst über das Spectrum des Andromedanebels ist nichts weiter bekannt, als dass er nicht das sonst bei Nebeln gewöhnlich vorkommende Gasspectrum zeigt."

I simply tried to present the evidence available to me and if the above presentation is unjust to Professor Scheiner, the injustice was not intentional on my part.

E. A. Fath

Pasadena
August 11, 1909

THE ASTRONOMICAL AND ASTROPHYSICAL SOCIETY

The Astronomical and Astrophysical Society of America held its tenth meeting at the Yerkes Observatory on August 18, 19, 20, and 21, with Professor E. C. Pickering, president, in the chair. Fifty-three members and a number of visitors attended the sessions.

The following forty-two papers were presented:

E. C. PICKERING: Opening Address by the President.

JOEL STEBBINS: "Some Results with a Selenium Photometer."

J. A. PARKHURST: "Precautions Necessary in Photographic Photometry."

HENRIETTA S. LEAVITT: "Standard Photographic Magnitudes."

J. C. HAMMOND: "Graduation Errors of the Circles of the Six-Inch Transit Circle of the U. S. Naval Observatory."

F. B. LITTELL: "The Pivots of the Nine-Inch Transit Circle of the Naval Observatory."

R. S. DUGAN: "The *Algol* System, *Z Draconis*."

K. LAVES: "The Problem of Three Bodies from the Standpoint of Spectroscopy."

K. LAVES: "Determination of the Moon's Theoretical Spectroscopic Velocity."

J. S. PLASKETT: "The Effect of Faulty Collimation of the Correcting Lens on the Star Image." (Lantern.)

E. B. FROST: "Lack of Spectroscopic Evidence of a Dispersion of Light in Space."

R. M. MOTHERWELL: "The Photographic Doublet of the Dominion Observatory." (Lantern.)

E. E. BARNARD: "On the Photographs of Comet c 1908 (Morehouse)." (Lantern.)

W. J. HUMPHREYS: "Vertical Temperature Gradients in the Atmosphere, as Determined by Season and by Types of Weather." (Lantern.)

E. W. BROWN: "New Plans for Tabulating the Moon's Longitude."

FRANK SCHLESINGER: "A Proposed Design for an Objective Prism Spectroscope for the Determination of Radial Velocities." (Lantern.)

W. J. HUSSEY: "Improvements in the Observatory at Ann Arbor."

J. S. PLASKETT: "The Width of Slit Giving Maximum Accuracy."

PHILIP FOX: "Solar Spectroscopic Observations."

R. H. CURTISS: "The New Spectroscopic Measuring Engine of the Detroit Observatory."

R. H. CURTISS: "The Focal Curves of the Single-Material Camera Doublet of the Single-Prism Spectrograph of the Detroit Observatory." (Lantern.)

R. H. CURTISS: "On Differential Flexure in the Single-Prism Spectrograph."

E. E. BARNARD: "On the Proper Motion of Some of the Small Stars in the Dense Cluster *M 92 Herculis*."

F. R. MOULTON: "Some Considerations on Globular Star Clusters."

W. J. HUMPHREYS: "A Proposed Method of Studying Solar Radiation at Great Altitudes."

E. D. ROE, JR.: "Achromatic and Apochromatic Comparative Tests."

E. E. BARNARD: "On Some Experiments in Photographing Enlarged Images of the Planets Direct with the Forty-Inch Telescope." (Lantern.)

W. W. CAMPBELL: "Report of Progress on the Radial Velocity Program of the Lick Observatory."

R. G. AITKEN: "Report of Progress in the Lick Observatory Double-Star Survey."

H. D. CURTIS: "Thirteen Stars Having Variable Radial Velocities."

H. D. CURTIS: "Three Stars of Great Radial Velocity."

H. D. CURTIS: "Spectroscopic and Photographic Observations of Comet c 1908 (Morehouse)."

S. ALBRECHT: "Note on the Apparent Wave-Lengths of Lines in the Different Spectral Types and in Certain Variable Stars."

MRS. W. P. FLEMING: "A Photographic Spectrum of a Meteor."

MISS A. J. CANNON: "A New Variable Star of the Class *R Coronae*."

W. J. HUMPHREYS: "Planetary Magnetism in the Sun."

E. C. PICKERING: "Unpublished Work of the Harvard Observatory."

W. H. PICKERING: "The Photographic Search for Planet O."

PHILIP FOX: "The Use of Quartz Fibers for Micrometer Wires."

EDGAR TILLYER: "The Clock Vault of the U. S. Naval Observatory."

E. C. PICKERING: "Present Needs of Astronomy."

G. H. PETERS: "On the Construction of Astronomical Photographic Objectives at the Naval Observatory." (Lantern.)

Reports of committees were also presented:

Committee on Comets. G. C. COMSTOCK, Chairman.

Committee on Luminous Meteors. CLEVELAND ABBE, Chairman.

The next meeting will be held at the Harvard College Observatory in August, 1910.

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Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right unless the author requests that the reverse procedure be followed.

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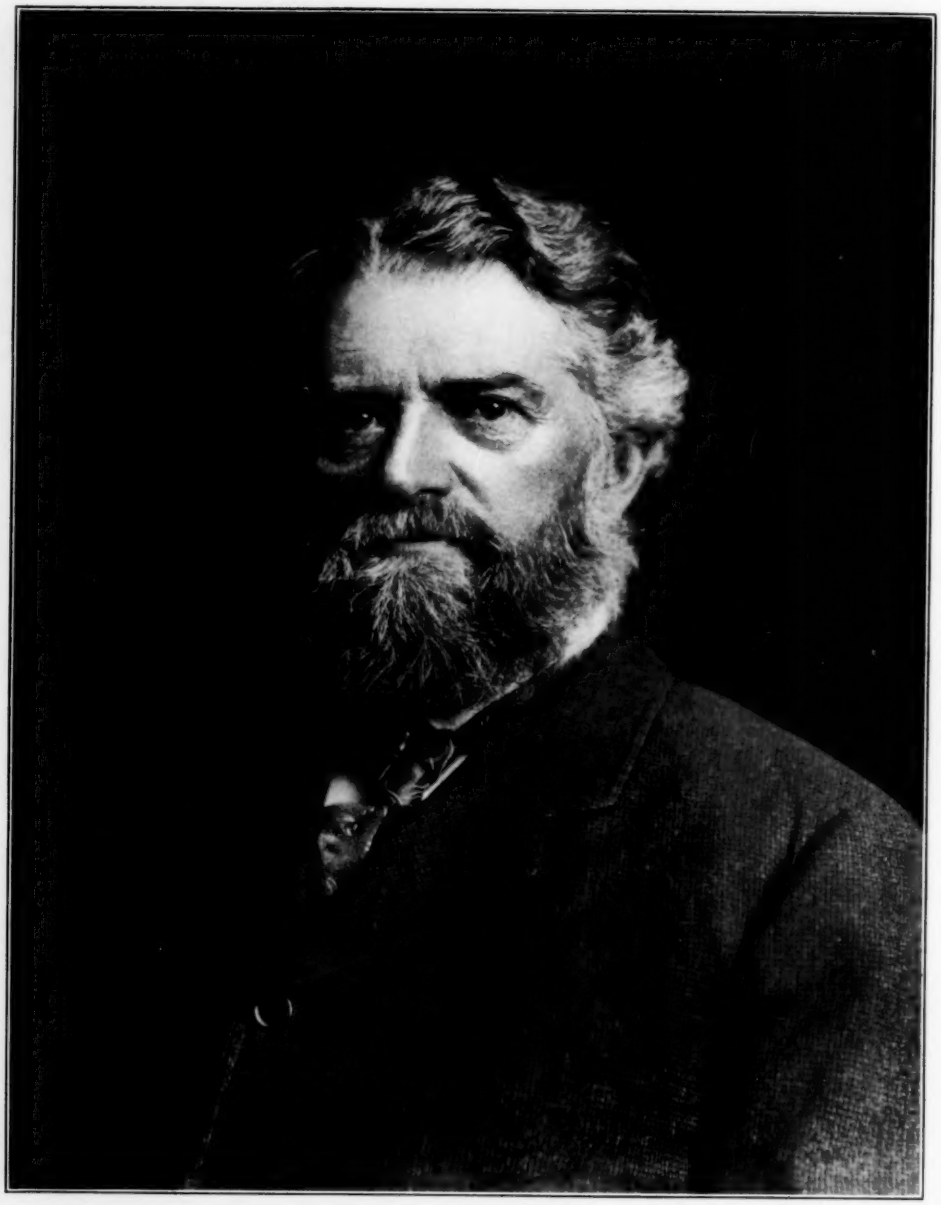

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